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# Emergenesis

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## *Genetic Traits That May Not Run in Families*

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***Traits that are influenced by a configuration rather than by a simple sum-of polymorphic genes may not be seen to be genetic unless one studies monozygotic twins (who share all their genes and thus all gene configurations) because such "emergenic" traits will tend not to run in families. Personal idiosyncrasies that have been found to be surprisingly concordant among MZ twins separated in infancy and reared apart may be emergenic traits. More speculatively, important human traits like leadership, genius in its many manifestations, being an effective therapist or parent, as well as certain psychopathological syndromes may also be emergenic. These ideas reemphasize the importance of the role played in human affairs by genetic variation.***

It is a common observation that monozygotic (MZ) twins tend to be remarkably similar, not just in appearance and aptitude but also in those idiosyncrasies of habit, taste, and style that constitute what we think of as human individuality. When the twins have grown up together in the same home, one is inclined to attribute these similarities to common experience, mutual modeling, and the strong attachment that is commonly seen in MZ twins from earliest infancy. Twin studies of metrical traits (e.g., IQ, personality, and interest traits), however, have found surprisingly little evidence for such effects of shared environment; the residual variance remaining in most of these traits after the genetic variance has been removed consists primarily of nonshared variance of environmental origin (i.e., unshared *threptic* variance; Cattell, 1982), plus components due to measurement error (e.g., Plomin & Daniels, 1987) and to the unsystematic secular variation that is characteristic of psychological traits (e.g., McGue, Bacon, & Lykken, in press). Moreover, studies of MZ twins who have been separated in infancy and reared apart (MZA twins) have also noted idiosyncratic similarities similar to those seen in MZ twins reared together (MZTs; e.g., Juel-Nielsen, 1965; H. H. Newman, Freeman, & Holzinger, 1937; Shields, 1962).

In the Minnesota Study of Twins Reared Apart (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990; Lykken, Bouchard, McGue, & Tellegen, 1992b), we too have been struck by the similarities in personal style within many of the MZA pairs whom we have studied over the past 12 years. While videotaping an interview with one twin, we discovered that he was an accomplished raconteur with a fund of amusing anecdotes, so, while

interviewing the co-twin, we asked him if he knew any funny stories. "Why, sure," he said, leaning back with a practiced air, "I'll tell you a story" and proceeded to demonstrate his concordance. A pair of British MZAs, who had met for the first time as adults just a month previously, both firmly refused in their separate interviews to express opinions on controversial topics; since long before they discovered each other's existence, each had resolutely avoided controversy. Another pair were both habitual gigglers, although each had been raised by adoptive parents whom they described as undemonstrative and dour, and neither had known anyone who laughed as freely as she did until finally she met her twin. Both members of another pair independently reported that they refrained from voting in political elections on the principle that they did not feel themselves well enough informed to make wise choices. A pair of male MZAs, at their first adult reunion, discovered that they both used Vademecum toothpaste, Canoe shaving lotion, Vitalis hair tonic, and Lucky Strike cigarettes. After that meeting, they exchanged birthday presents that crossed in the mail and proved to be identical choices, made independently in separate cities.

There were two "dog people" among the MZA individuals; one showed her dogs, and the other taught obedience classes—they were an MZA pair. Only two of the more than 200 individual twins reared apart were afraid to enter the acoustically shielded chamber used in our psychophysiology laboratory, but both separately agreed to continue if the door was wired open—they were a pair of MZA twins. When at the beach, both women had always insisted on entering the water backwards and then only up to their knees; they were thus concordant, not only in their phobic tendencies but also in the specific manifestations of that timidity. There were two gunsmith hobbyists among the group of twins: two women who

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habitually wore seven rings; two men who offered a (correct) diagnosis of a faulty wheel bearing on Bouchard's car; two who obsessively counted things; two who had been married five times; two captains of volunteer fire departments; two fashion designers; two who left little love notes around the house for their wives, ... in each case, an MZA pair.

Some of these similarities were surely coincidence; for example, one pair of twins had both divorced women named Linda and then married women named Betty. When any two biographies are avidly compared, at least some overlap is likely to be found. These same men discovered that, for several years before they met one another, they had both vacationed in Florida on the same stretch of beach, driving down there in the same model Chevrolet. They both had named their sons "James Alan" (one "Allan") and both chain-smoked *Salems* with nail-bitten fingers while at work in their basement woodshops. The dizygotic separated in infancy and reared apart (DZA) twins whom we have studied, in contrast, seldom produced similar "coincidences": the one striking exception was a pair of DZA men who both had prison records and histories of drug abuse and who both were decorated with numerous tattoos.

These anecdotal observations are suggestive in the "context of discovery," and what they suggest is the existence of genetic traits that do not run in families. That is, if these idiosyncratic similarities of MZA twins are not all mere coincidence, then it is likely that they are related to the genome common to both twins (i.e., that these similarities are of genetic origin). Because they are seldom seen in DZA twins, it is doubtful that these similarities would be often seen in other pairs of first-degree relatives (i.e., it is unlikely that they are familial). The standard models of behavior genetics require that genetic traits must also be familial. As we review below, however, there is other evidence of qualitative genetic traits that do not run in families. The **standard polygenic-additive** model for continuous or metrical traits predicts that pairs of relatives will be correlated in proportion to their genetic correlation. Yet, as we show, there is also evidence of metrical traits for which the MZ correlation is high, indicating a genetic basis, whereas the DZ correlation is insignificant, indicating that the usual family or adoption studies would be unlikely to reveal the genetic **understructure**.

The existence of genetic traits that are not (or are only weakly) shared by first-degree relatives would be evidence for a neglected mechanism of non-additive or **configural** genetic determination (Eaves, 1987; Grayson, 1989; Heath, Martin, Eaves, & Loesch, 1984; Li, 1987; Lykken, 1982; Lykken, Tellegen, & Iacono, 1982). Before developing this argument, however, we will review the standard model.

### Genetic Variation: The Standard Doctrine

The genome, the entire collection of genes arranged on their 46 chromosomes, can be thought of as a blueprint or, better, a very large book of instructions, each of the

approximately 100,000 pages representing a different gene. Nearly three fourths of these pages are identical for all normal individuals (Lewontin, 1967); because they do not vary within species, we can call these **monomorphic** genes. Some of them we share with other mammals, and most of them we share with the higher apes. Only a relative handful of our full set of monomorphic genes cause us to develop into the primate called *Homo sapiens* rather than the ones called *Pan troglodytes* or *Gorilla gorilla*. The remaining pages of our instruction book represent **polymorphic** genes. As we look across the population, we find from 2 to as many as 20 or more variations of each page-different forms or **alleles** of each polymorphic gene. It is the polymorphic genes that are responsible for individual (genetic) differences within a species.

Mendelian traits, such as the red blood cell antigens or blood types, are determined by which of the possible alleles are present in one particular gene locus on a pair of homologous chromosomes. Scores on metrical traits, traits like stature or IQ in humans or milk production in cows, are thought to be determined to the extent that they are **genetically** determined by the combined action of many genes. Such traits are expected to fit a **polygenic-additive** model. This model assumes that each participating **polygene** contributes its **fungible** bit to the total result. These genes are on different chromosomes, or far apart on the same chromosome, so that they segregate independently when the parental genome divides into two approximately random halves to form the nucleus of an egg or sperm.

Thus, the father passes on to each offspring a random half of all his genes and maybe less, maybe more, than half of all his "tall" genes. This paternal contribution combines with whatever fraction of the mother's tall genes happens to be included in the ovum, and the sum of these components determines genetic stature. MZ twins have identical **genotypic** stature. (As a result of environmental differences such as marked differences in placental nutrition, some MZ twins differ by several inches in **phenotypic** height; nonetheless, MZ twins correlate approximately .94 in stature even after correction for age and sex.) DZ co-twins (and other sib pairs), who represent two different random samples from the same parental gene pool, share by common descent approximately 50 percent of their polymorphic genes (as distinguished from the monomorphic genes shared by all normal members of the species). The fraction of the parental tall genes apportioned to each DZ twin—his or her genetic **height**—will be about half as similar within pairs as for MZ twins (a little more than half, actually, because of assortative mating for stature). Indeed, same-sex DZ twins correlate about .50 in height (e.g., Lykken, 1982, p. 365).

This rule, that pairs of relatives correlate in proportion to their genetic correlation, applies generally to polygenic-additive traits. A polygenic-additive model explains why these familiar genetic traits tend to run in families. And that is why polygenic-additive traits are easily recognized as features of interest to geneticists: They run 'in families. But this is not the **only** way

in which genes contribute to the quantitative variation within a species, to individual differences. Indeed, the polygenic-additive model seems a very curious way of describing the way in which genes actually work (see Murphy, 1979).

The mammalian eye and the hominid hand with its opposable thumb are multigenic, but they are not constructed additively. If, at conception, one is short-changed on eye genes, one does not develop a smaller but otherwise normal eye. Like all the organs specified in the species plan, eyes and hands are fabricated in a complex, sequential process, an assembly line in which each stage depends on the one preceding and in which every worker-every gene-plays a pivotal role. This process is not additive but, rather, *configural*; all of the components are essential, and the absence of, or a change in, any one (i.e., in any gene) can produce a qualitative or a large quantitative change in the result. The familiar Mendelian genetic abnormalities can be attributed to single genes not because one gene orchestrates the entire syndrome but because, in the polygenic configuration that manufactures the normal system, a one-gene change makes a qualitative difference in the product. Dawkins (1982b, pp. 22-26) made the same point.

These organs and attributes are emergent properties of configurations of monomorphic genes, configurations that we all share as part of being human. Polymorphic genes, the ones responsible for individual differences, can also behave configurally. Human lymphocyte antigens (HLA) are a nice example. Most body cells are marked by a group of special proteins, antigens, that function as a kind of brand or code, identifying your cells as yours and someone else's tissue as foreign. Each HLA antigen is coded for by a gene that is highly polymorphic-has many allelic forms-so the chances that two friends have any particular antigen may be only 1 in 10 or 20. The probability that they match on the whole set of HLA antigens is vanishingly small because there are hundreds of millions of different combinations. This *histocompatibility* code is configural in the same sense as a telephone number: Change even one digit in a phone number and you get the wrong party: change just one antigen in the histocompatibility code and the transplanted kidney may be rejected.

It happens that the antigens most important in tissue rejection are coded for by genes close together on the same chromosome so that they do not segregate independently but are usually passed from parent to offspring as a package. For this reason, one has a reasonable chance of finding a close relative whose tissues match well enough to risk a transplant. Traits that depend on configurations of polymorphic genes that *do* segregate independently will be shared by MZ twins, who share all their genes and hence all gene configurations, but are much less likely to be shared by DZ twins, siblings, or parents and offspring. Such traits, although genetic, would not tend to run in families.

## Genetic Traits That Do Not Run in Families

### *Frequency of the Alpha Rhythm*

The spectrum of the resting electroencephalogram (EEG; i.e., the graph of the relative amount of brain wave activity at each frequency from, say, 0.1 hz to 20.0 hz) is rather like a fingerprint in that its shape varies from person to person but is quite constant for the same person over time. In two experiments (Lykken, Tellegen, & Thorke-son, 1974; Lykken et al., 1982), we obtained EEG spectra from a total of 147 pairs of adult MZ twins and 53 pairs of DZs. We analyzed each spectrum into its five main components: the amount of EEG activity in the four classical EEG frequency bands, called delta, theta, alpha, and beta; and the midfrequency of the alpha component, a parameter that we called phi. Then we computed the within-pair correlations for each of these parameters. The MZ twins correlated about .80 for all five, and the DZ correlations averaged .40 for the first four parameters, as would be expected with polygenic-additive variables. But the DZ correlation for phi was .13, only about one sixth rather than half of the MZ value. The midfrequency of the alpha rhythm, because it is so weakly correlated in DZ co-twins, is unlikely to be strongly correlated among first-degree relatives generally. Yet, because the MZ correlation is very high even among MZA twins (see Table 1), phi must be strongly genetic, even though it does not tend to run in families.<sup>1</sup>

This is interesting because, although no one knows exactly how the alpha frequency is determined biologically, it probably involves some sort of resonance phenomenon (e.g., Fedotchev, Bonda, & Konovalov, 1990). Resonance is a classic example of a non-additive *configural* phenomenon. In electronics, for example, the resonant frequency of a circuit is a function of the *product* of inductance and capacitance. The pitch and timbre of the human voice is determined by the resonant characteristics of the vocal apparatus, the shape and musculature of the vocal chords, the glottis, the hard palate, the nasopharynx, and so on. The properties of each of these components are genetically, and largely independently, determined. For this reason MZ twins, whether reared together or apart, have very similar voices and can easily substitute for one another on the telephone. In her review of the MZA literature, Farber (1981) said, "The pitch, tone, and overall characteristics of the twins' voices were so stunningly alike that almost all investigators made mention of the similarity" (p. 85). Ordinary siblings,

<sup>1</sup>Stassen, Lykken, Propping, & Bomben (1988) confirmed that the EEG spectra of MZA twins are about as similar within pairs as between retests of the same individuals. Propping (1977) also found that the correlation within 24 pairs of DZ twins for amount of alpha and beta activity was approximately half the MZ value. Propping's twins then consumed a standard dose of ethanol, and the EEG was repeated after two hours when the EEG effects of alcohol were at a peak. The MZ correlations for beta and alpha activity were still high (.74 and .80), whereas the DZ correlations had decreased to zero (-.09 and -.01). Thus it appears that the electrocortical response to alcohol challenge is an emergent trait.

Table 1

Examples From the Minnesota Twin Studies of Metrical Traits for Which the MZ Correlations are Substantial and the DZ Correlations Weak, Suggesting That the Traits are Emergent

Variable	MZT	MZR	MZA	DZT	DZR	DZA
<b>EEG spectrum parameters</b>						
No. of pairs	89		38	53		
Alpha midfrequency	.81		.80	.13		
<b>Personality traits</b>						
No. of pairs	553	131	52	459	74	33
MPQ Well-being	.44	.68	.53	.11	.12	-.04
<b>Electrodermal habituation</b>						
No. of pairs	36		43	42		
Rate of habituation	.72		.54	.05		
<b>Interests and talents</b>						
No. of pairs	503	102		390	96	
Arts and crafts	.51	.63		.14	.07	
<b>Self-ratings</b>						
No. of pairs	503	102		390	96	
Well-adjusted	.44	.53		.10	.02	

Note. MZ = monozygotic; MZT = Adult MZ twins reared together; MZR = MZT twins retested after 2-10 years, mean scores correlated; MZA = MZ twins reared apart; DZ = dizygotic; DZT = DZ twins reared together; DZR = DZT twins retested after 2-10 years; DZA = DZ twins reared apart; EEG = electroencephalograph; MPQ = Multidimensional Personality Questionnaire. Data updated from Lykken, 1982; Lykken, Iacono, Haroian, McGue, & Bouchard, 1988; Lykken, Bouchard, McGue, & Tellegen, 1990; Tellegen, et al., 1988; Waller, Lykken, & Tellegen, in press.

however, seldom have really similar voices. A recent study by Stearns and VanderWoude (1991) found that students of voice, like music students generally, more often have musically talented parents than do arts college students not majoring in music. The proportion of parents who are gifted singers, however, was no greater for vocal students than for instrumentalists. Serious singers need to be musical, a trait that seems to run in families, but they also need a mellifluous voice, a trait that may be emergent.

### Beauty

Facial beauty (or handsomeness; there is no gender-neutral term in English) similarly is a function not of the sum but of the configuration of facial features. Admittedly from time to time one sees individual features that would spoil almost any face, but as a rule the attractiveness of a given nose or chin or pair of ears depends to an important extent on the context of the other features. This is easily demonstrated by asking an artist to imagine a mating of two conventionally beautiful people; our artist used two television actors. When she had sketched these two faces, we asked her to construct the faces of possible male and female offspring of this mating by arbitrarily reassembling the features of the imagined parents. A reasonable conclusion, based on the results of this experiment as shown in Figure 1, is that comeliness is emergent.

### A Psychiatric Example

Abrams (1986), a psychoanalyst, described a pair of female twins who were separated in early infancy and separately placed in rather different but equally promising

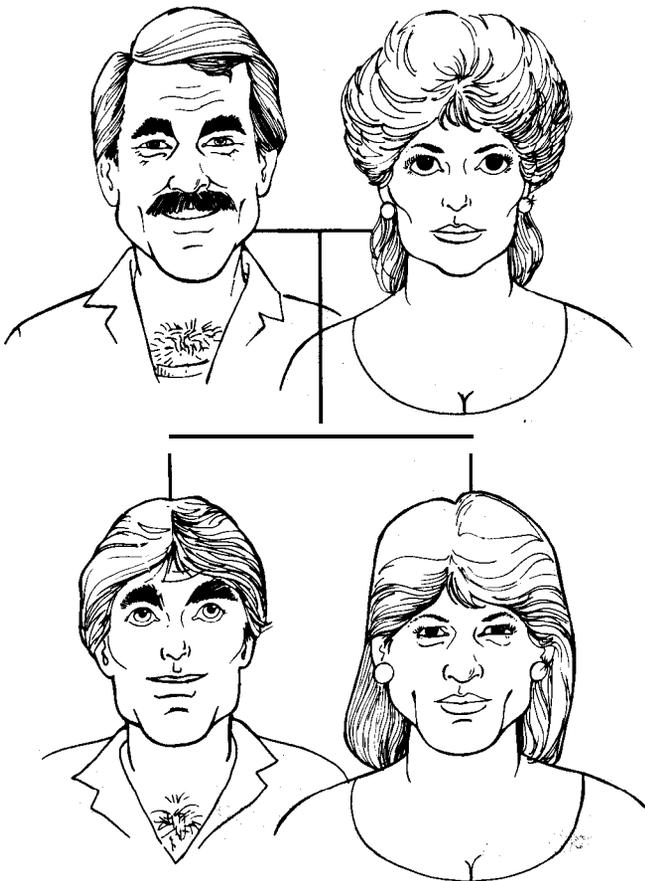
adoptive homes. After an unexceptional first year, problems began to develop in both children. By age 10, both children were said to have "serious disorders," albeit rather nonspecific ones. "The two are *equivalently* pathological: they share a limited development; they share a timetable of emergence, an excess of expression, and a channelization of symptoms; they share character disturbances; they share a quality of shallowness and a limited self-definition: they are poorly integrated; they share comparable cognitive deficiencies" (p. 43).

What is especially interesting about this report is the author's acknowledgement that, if the children had been studied as singletons, most clinicians would have found it easy to explain their problems in terms of their different family environments. Indeed,

They might even have speculated along these lines: If Beth had only had the dominant features of Amy's family—the confrontative mother, the strong father, the successful brother, the value of academic achievement—or if Amy had only had the dominant features of Beth's family—the overly accepting mother, the evenly attentive father, the less successful brother, the lack of concern about education—how much better each would have fared! (Abrams, 1986, pp. 52-53)

Only the fact that these girls were MZA twins forced this research team to the realization that they were dealing with a syndrome that had genetic roots, a novel *configuration* of disabilities that manifested itself in both girls, not because of but in spite of the differences in their family environments, environmental features that these clinicians would otherwise have regarded as significant and even causal.

Figure 1  
*Comeliness Is Emergenic*



Note. Top: Artist's conception of the conventionally handsome faces of two American actors. Below: The artist represents two offspring who might have resulted from these parents. The facial features of the parents have been randomly reassorted (excluding head and body hair). Results suggest that, within limits, attractiveness of a facial feature depends on the context of the other features (i.e., that facial beauty is in some degree configural or emergenic).

### Emergenesis

It is useful to have a name for this odd type of trait, a trait that is an emergent property of a configuration of genes or perhaps a configuration of more basic traits that are themselves partly genetic in origin. Lykken (1982) proposed the term *emergenic* for this purpose.

**emergenic** (*adj*) Arising as a novel or emergent property resulting from the interaction of more elementary and partly genetic properties. An emergenic trait might be determined by a configuration of independently segregating polygenes interacting in the sense of epistasis, or, at a more molar level, an emergenic trait might be a property of a configuration of independent traits that are themselves in part genetically determined. In some instances (see *Impact Traits*, below) situational factors may figure as configural components. The distinctive feature of emergences is the notion of configurality, which implies that any change of any one component may result in a qualitative, or a large quan-

titative, change in the emergenic trait. Emergenic traits may—but are likely not to—run in families. On the other hand, marked MZ similarity combined with weak similarity of DZ twins is strongly suggestive of an emergenic trait.

What we suggest now is that perhaps many complex human psychological traits (e.g., many of the idiosyncrasies of personal style that we have observed in twins), as well as traits like extraversion; the ability to stop reacting to a meaningless repeating stimulus (habituation); more familiar traits like leadership, artistic ability, selling ability, teaching ability, creativity, parenting ability—and also many examples of human genius—are emergenic traits. Because these attributes do not tend to run in families, the possibility of their having a genetic basis has been overlooked. As we have seen, we will not discover the emergenic character of such traits unless we study twins. Until this idea is more broadly accepted, we will not *believe* what we discover unless we study twins reared apart.

### Metrical Emergenic Traits

#### Extraversion

In the case of metrical traits, emergence is suggested when the intraclass correlation of MZ twins is substantially greater than twice the DZ correlation, as is true of the midfrequency of the EEG alpha rhythm discussed above. This is also true for the trait Eysenck (1952) identified as extraversion, Cattell (1956) as *exvia-invia*, and Block (1965) as ego control. Extraversion is one of the small set of temperament traits or superfactors that are found in factor analyses of personality traits or first-order factors. Jinks and Fulker (1970) attempted to fit a polygenic-additive model to extraversion data and found that the too-weak DZ similarity caused their model to yield nonsensical results. To account for their findings, Jinks and Fulker proposed that, while growing up together, DZ twins tend to “react against each other in such a way as to develop opposite characteristics with respect to a trait” (p. 333). Eaves (1976) proposed a competitive model with somewhat different properties. In their study of 850 sets of twins recruited from students who took the National Merit Scholarship test, Loehlin and Nichols (1976) subjected the contrast hypothesis to a number of empirical tests and found it wanting. In particular, of course, this hypothesis cannot explain why DZA twins would be much less than half as similar in extraversion as are MZA twins. Using a population-based sample of Swedish twins, including 315 pairs reared apart since age 10, Pederson, Plomin, McClearn, and Friberg (1988) administered a nine-item version of the Extraversion scale from the Eysenck Personality Inventory (EPI), obtaining MZA and MZT correlations of  $.30 \pm .09$  and  $.54 \pm .06$ , respectively, compared with  $.04 \pm .07$  and  $.06 \pm .07$  for DZAs and DZTs. The Well-Being scale of the Multidimensional Personality Questionnaire (MPQ; Tellegen & Waller, in press) measures a facet of extraversion. Lykken et al. (1992b) reported correlations for Well-Being of  $.44 \pm .03$  in MZT twins ( $.53 \pm .14$  in 52 pairs of MZAs) but only

.11 ± .04 in DZT twins (−.04 ± .18 in DZAs; see Table 1).

### *Electrodermal Response and Habituation*

Lykken, Iacono, Haroian, McGue, and Bouchard (1988) subjected 121 pairs of adult twins, some reared together and others reared apart, to a series of 17 relatively unpredictable 105-db tones while measuring their electrodermal responses (EDRs) in a habituation paradigm. Both the MZT and the MZA twins were strongly correlated (.72 ± .17 and .54 ± .16, respectively) in the slope of the curves describing their habituation to these tones. The combined group of 42 pairs of DZT and DZA twins, however, was negligibly correlated (.05 ± .16) on these variables (see Table 1).

### *Interests and Talents*

Inventories of occupational and recreational interests and of self-rated talents, a total of 291 Likert-type items, were administered to more than 4,000 middle-aged participants of the Minnesota Twin Registry; in some 900 pairs, both twins completed all the inventories (Lykken, Bouchard, McGue, & Tellegen, 1992a). Factor analyses of the 291 items for men and women separately yielded 39 factors congruent in both sexes. After three years, 198 twin pairs were retested, of which 53 pairs were female MZs, 52 were female DZs, 49 were male MZs, and 44 were male DZs. By testing twins twice over a lengthy time span, one can obtain improved estimates of within-pair similarity with respect to the *stable* component of their self-rated traits, partly disattenuated by both measurement error and also by the unsystematic variation about the stable *setpoint* that we believe to be characteristic of psychological traits. Some improvement is achieved by correlating the mean of the scores obtained at Time 1 and Time 2 as shown in Table 1.

These twins, who had been reared in the same families, had similar interest (or lack of interest) in hunting and fishing and in visiting casinos or race tracks, playing poker, and engaging in other forms of gambling. The DZ similarity was actually more than half the MZ value for both gambling and blood sports, suggesting that shared rearing environment influenced these interests. These middle-aged MZ twins were also very similar in the factor we called arts and crafts; the correlation for 503 pairs of MZ twins tested once was .51 (±.04), and for 102 pairs tested twice three years apart, the mean arts and crafts score correlated .63 (±.10). The DZ similarity, however, was much weaker for this factor (which combined interests and self-rated talents): .14 (±.05) for 390 DZ pairs and only .07 (±.10) for the mean of two testings of 96 pairs (see Table 1). Assuming other first-degree relatives are no more alike than DZ twins, we conclude that, among adults, interest in arts and crafts is only faintly familial at best. Noting that MZA twins are nearly as similar on these interest and talent traits as MZTs are (Lykken et al., 1992a), we can say that at least half the stable variance in arts and crafts was based on genetic factors. This in-

terest/talent factor therefore, appears to qualify as an emergenic trait.

Among the most clearly emergenic of the self-rated traits in this study was what we called the well-adjusted factor. The MZ correlation was .44 (±.04) compared with the .10 (±.04) for DZ twins tested once and .53 (±.10) versus .02 (±.10) for the mean of two testings (see Table 1). The Likert-type items that make up the well-adjusted scale ask about optimistic outlook, contentment, sense of personal worth, emotional control, coolness under stress, affability, and capacity for happiness. This scale appears to be related to the ubiquitous extraversion *superfactor*, which as we have seen is itself emergenic.

### **Structure of Metrical Emergenic Traits**

As we have defined *emergenic* above, any nonlinear function of two or more partially genetic traits is **emergenic** (whether a given variable, thus defined, is a trait unity, a natural or useful parameter of the individual, is a separate question). But it is not the case that all nonlinear functions of several independent genetic traits yield variables that are not familial. Thus, for example, if we measure stature (S), fingerprint ridge count (R), and IQ (Q) on a large sample of twins, convert each variable to standard-score form, and take the product, then  $E = SRQ$  is emergenic. If, however, we let the variables take on only positive values, say, with a mean of 50 and a standard deviation of 10, then the MZ correlation for E will be substantial, and the DZ correlation will still be approximately half the MZ value. That is, the linear-additive model can often closely approximate the effects of an underlying structure that is nonlinear. As Anderson and Shanteau (1977) pointed out, merely showing that a linear regression equation can make accurate estimates cannot be taken as evidence that the predictor variables actually combine additively. Thus, the fact that E is emergenic (configural) would not be deduced even from twin data because E behaves like a familial trait.

We know from the examples cited earlier, however, that some emergenic traits do not run in families. One simple nonlinear function that may yield such a result is the squared difference (SQD) of two underlying traits. For instance, using data from some 1,200 pairs of adult twins from the Minnesota Registry, we converted both height (HT) and weight (WT) to age- and sex-corrected T-score units ( $M = 50$ ,  $SD = 10$ ) and then computed  $SQD = (HT - WT)^2$  for each individual. SQD is low for people whose weight is proportionate to their height, high for those who are tall and thin or short and fat. The MZ correlation for SQD is  $0.64 \pm .02$ , and the DZ value is  $0.15 \pm .04$ . Therefore, we can reasonably conclude that SQD is an emergenic trait. Whether it has scientific interest, of course, remains to be seen. It is not unreasonable to suppose that psychologically interesting traits of this type do exist, traits that depend on the balance between two or more component traits.

Nonfamilial metrical traits can also result from an aggregate or sum of threshold traits. For example, if  $X_i$

is the  $i$ th component trait, and if  $W_i$ , the  $i$ th weight, equals 1.0 if  $X_i > \text{threshold}$  and zero otherwise, then

$$Y = W_1X_1 + W_2X_2 + \dots + W_kX_k$$

will be a nonfamilial additive trait, provided that the  $X_i$ s are heritable and  $P(X_i > \text{threshold})$  is small. If  $W_i$  depends, say, on  $X_j$  rather than on  $X_i$ , then the aggregate will be configural-emergenic—as well as nonfamilial. To illustrate this idea, an American child's potential for becoming a football running back might be an aggregate of strength, running speed, balance, fearlessness, and resistance to injury, but with each variable contributing to the total only if the next-listed variable is above some relatively high threshold.

Child development seems to involve many threshold situations—fighting versus backing off, yielding to temptation versus not yielding, succeeding versus failing, daring versus not daring, and so on. The child whose aggressiveness, impulsiveness, talent, or fearlessness is just slightly above the threshold level may subsequently have qualitatively different experiences from—and become emergentically different from—his or her siblings. To the extent that the genome tends to determine the child's effective environment—the experiences, that is, that create these threshold situations (Lykken et al., 1992b)—to that extent will MZ twins, and even MZA twins, tend to develop the same emergenic traits.

### *Emergenesis Versus Epistasis*

Geneticists would say that emergenic traits result from *epistasis*, defined as the nonreciprocal interaction of nonallelic genes. But it is customary to subsequently disregard this component in applications of the general model, either on the assumption that epistatic effects will be minimal (e.g., Jinks & Fulker, 1970) or in the frank recognition of the difficulties of testing for epistasis in human family data (Cavalli-Sforza & Bodmer, 1971). Murphy (1979) remarked that the inclusion, in the partitioning of the phenotypic variance, of a term identified as “epistasis, etc., the chief property of which is that it fills a hole in a balance sheet” (p. 132) provides the biometrical geneticist with an illusory sense of having covered all the bases. “What results is not science but devious accountancy” (p. 132). Heath et al. (1984) published what they believed to be “the strongest evidence so far for polygenic epistasis in man” (p. 719). This evidence, involving counts of the number of fingerprint tri-radii, consists of high (.90) correlations in 110 pairs of MZ twins combined with lower (from .24 to .41) correlations in 111 pairs of DZ twins and in hundreds of sibling and parent-child pairs. Heath et al. pointed out that the effects of dominance and Additive X Additive Epistasis can be resolved with the addition of parent-child data to the data for twins. The examples of non-additivity in psychophysiological, interest, and personality variables that we have reported have all involved similar or larger ratios of MZ to DZ correlations, although still larger samples and the addition of twin family data will be needed to confirm these findings.

However, the idea of a configural relationship conveys more than interaction, and some of the emergenic traits discussed herein are more naturally described at the molar level, as configurations of partly genetic traits, than at the level of interacting polygenes (although see Li, 1987). Most phenotypic traits, and certainly most psychological traits, are many steps removed from genetic activity, so far removed that attempts to understand any surface (metrical) trait in terms of specific gene action seem premature if not presumptuous. It is more plausible to suppose that the behavior genetics of the future will assume a hierarchical structure in which surface traits are seen to be functions of source traits that are, in turn, determined by dispositions at a lower level, and so on. If one is interested in the trait of leadership, for example, it seems sensible to analyze it in terms of other more basic psychological variables rather than to start searching for enzymatic correlates.

### *Impact Traits*

Charismatic leadership, selling ability, parenting success, interpersonal attractiveness, entrepreneurial ability, and many other important dimensions of individual difference are difficult, perhaps impossible, to define solely in terms of characteristics of the actor without reference to the impact of his or her actions on the (primarily social) environment (Lykken, 1991, p. 18). Measures of such traits must often be configural, rather than additive, functions of the relevant intrapsychic and environmental components. Suppose, for example, two great leaders like Gandhi and Churchill could by some magic have undergone a random interchange of certain salient traits: surely both would then have been diminished in their leadership ability, just as two prize-winning cakes might be ruined by a random exchange of certain ingredients (e.g., one egg vs. six). The recipes for leadership, like the recipes for cakes, seem likely to be configural rather than additive. Even a total exchange of psychological characteristics might have been disastrous; Gandhi's simplicity and saintliness might not have dealt effectively with Hitler's war machine, and Churchill's bombast and epicurean self-indulgence would not have endeared him to the Indian masses.

Because it encompasses configurations, not just of polygenes but of partly genetic component traits and even of situational factors in the case of impact traits, *emergensis* seems to have a broader and psychologically more useful scope than *epistatic*.

### *Qualitative Emergenic Traits*

#### *Secretariat*

Old-fashioned hereditarians used to make much of the notion of breeding, a concept that has been pushed to the extreme by exponents of the sport of horse racing. Through careful breeding in the early part of the last century, the thoroughbred race horse became steadily stronger and faster, and the record times recorded at old English race courses steadily fell. Along about the turn

of this century, however, this curve leveled off as the initial additive variance was bred out of the line (e.g., Cunningham, 1991). The modest improvements in performance over the next 70 years or so are largely attributed to better training, nutrition, and veterinary techniques.

And then along came Secretariat, a great red stallion who lay down and took a nap on the day of his Kentucky Derby and then got up and broke the course record, not by just a whisker but by seconds. He did the same thing at Pimlico and then won the Belmont and the Triple Crown by more than 30 lengths. Put out at once to stud, where only the most promising mares could afford his fees, Secretariat sired more than 400 foals—most of them disappointments, none of them remotely in their sire's class. Secretariat had a distinguished lineage, of course, although none of his forebears could have run with him, but whatever he received at the great lottery of his conception could not be easily passed on in random halves. It seems a reasonable conjecture that Secretariat's qualities were configural, emergenic.

At last, in 1988, one of Secretariat's sons, Risen Star, finished third in the Kentucky Derby, won the Preakness, and then won the Belmont by some 14 lengths, albeit a full two seconds behind his sire's record pace. After more than 400 attempts, Secretariat managed to produce a winner; although emergenic traits do not run in families, they are more likely to reappear in a carrier family than in a random lineage. No doubt Risen Star's dam contributed key elements of the emergenic configuration.

It may be in this chancy way that evolution sometimes makes its qualitative steps onward after periods of stasis; it may be that Secretariat was one of Goldschmidt's (1940) "hopeful monsters" awaiting a similarly configured mate with whom he might breed true. For such an emergenic trait to play a role in equine evolution requires the occurrence of a critical mass of **traited** individuals in the same time and place, at least one stallion and two or several mares who, by interbreeding, might have the chance to found a race of superior horses. If the S (Secretariat) trait were based on a five-locus, **homozygous-recessive** configuration (as in Li's example, discussed below), then such a stallion would occur only once in 20 million random matings. But, if a million ancestral horses roamed the steppes of Central Asia during the early Pleistocene, producing  $2 \times 10^5$  foals each year, the odds would favor the appearance of a **traited** stallion approximately every 70 years. Ancestral horses probably traveled like wild horses do today, either in bands of bachelor males or in harems of mares headed by a single stallion (Anthony, Telegin, & Brown, 1991). We shall assume that **S-traited** horses would be substantially stronger and faster and thus able to compete successfully and that patriarchs of harems were able to sire, say, 200 foals over the course of their reigns.

A **traited** stallion would be likely to become a harem patriarch. The offspring of an affected sire would carry at least one of the required recessive genes at each of the five loci. Each 120 matings between such half-sibs would be likely to reproduce the emergenic trait. Moreover, at

least one in 11 patriarchs would (with  $p > .5$ ) produce a **traited** foal in the first filial generation. A **traited** filly produced in this way, if she remained in the paternal harem, would produce only **traited** foals. If a **traited** foal of the patriarch (or of his daughter) was a colt, he would be destined to become a patriarch himself and, at minimum, to start the lottery again without another 70-year wait. He might also produce carrier offspring contiguous in time and place to the harem of their affected grandsire. Any aged **traited** patriarch might in time be replaced as harem leader by one of his untraited sons who, interbreeding with his paternal half-sisters, would be likely to produce several **traited** offspring during his **regnancy**.

Not every contiguous appearance of **traited** mating partners will suffice to found a dynasty, of course, but each appearance of a **traited** stallion would generate a reasonable chance of such an outcome, through breeding with or among his offspring, and this chance would recur at least every 100 years or so. This dependence on inbreeding, with its perils of deleterious recessive traits, might reduce the competitive advantage of some **traited** offspring, although the mating of half-sibs carries only the slight genetic risk of cousin matings.

Note that the qualitative evolutionary step we are describing requires merely a novel recombination of existing alleles rather than an unlikely macromutation (see Dawkins, 1982a). Like the accepted mechanism of accumulating micromutations (which it would supplement and not replace), emergenic evolution also requires long spans of evolutionary time. Yet it may be that important saltations, like the appearance of the hominid opposable thumb, occurred in just such a way.

Although running speed is, of course, a metrical variable, Secretariat so far exceeded the limits of the normal distribution as to suggest a qualitative difference, a new natural class or **taxon** (see Meehl, 1992). The arena of human achievement appears to offer many similar examples, individuals whose accomplishments so far exceed the norm that we classify them separately from the common herd. An important example of such a class includes those people we call *geniuses*.

### **Genius**

How did it come about that a man born poor, losing his mother at birth and soon deserted by his father, afflicted with a painful and humiliating disease, left to wander for twelve years among alien cities and conflicting faiths, ... suspected of crime and insanity, and seeing, in his last months, the apotheosis of his greatest enemy—how did it come about that this man, after his death, triumphed over Voltaire, revived religion, transformed education, elevated the morals of France, inspired the Romantic movement and the French Revolution, influenced the philosophy of Kant and Schopenhauer, the plays of **Schiller**, the novels of Goethe, the poems of Wordsworth, Byron, and **Shelly**, the socialism of Marx, the ethics of Tolstoy, and, altogether, had more effect upon posterity than any other writer or thinker of that eighteenth century in which writers were more influential than they had ever been before? Here, if anywhere, the problem faces us: What is the role of genius in history? (Durant & Durant, 1967, p. 1)

In these celebrated first sentences of their *Rousseau and Revolution*, Will and Ariel Durant posed as well the psychological problem of genius itself, its mysterious irrepressibility, and its ability to arise from the most unpromising of lineages and to flourish even in the meanest of circumstances.

Human genius has always been a problem for both environmentalists and hereditarians to understand (Galton, 1869; Kroeber, 1944; Simonton, 1988.) There have been families of genius, of course—the Bernoullis and the Bachs, the Darwins and the Huxleys, the musical Marsalis family—but it is the solitary genius, rising like a great oak in a forest of scrub and bramble, who challenges our understanding. Carl Friedrich Gauss, ranked with Archimedes and Newton as one of the “princes of mathematics,” had uneducated parents. His mother was illiterate, yet the boy had taught himself to read and to do simple arithmetic by the time he was 3 years old (Buhler, 1981). When Gauss was 10, the village schoolmaster thought to keep his large class occupied by writing down the integers from one to 100 and then finding their sum. Moments later he was startled to see little Carl at his desk with just a single number on his slate. “There ’tis,” said the boy and then sat with his hands folded while the rest of the class toiled on. In the end, only Carl had the correct answer (Dunnington, 1955). The boy had at once perceived that the problem reduced to  $(1 + 100) + (2 + 99) + \dots + (50 + 51) = 50(101) = 5,050$ . To believe that some extraordinary accident of experience created this prince out of ordinary clay is to believe in magic.

The great Hindu mathematician, Srinivasa Ramanujan, whom Mark Kac called a magical genius (Kolata, 1987), was reared in a one-room adobe hut in southern India, and his mathematical education consisted primarily of two books, both in a foreign language (Borwein & Borwein, 1988). In 1913, with the help of a better educated friend, Ramanujan wrote from Madras to the great G. H. Hardy at Cambridge, asking his opinion of some 120 theorems that were enclosed. Hardy reported that some of these were classical although obscure; others were in Hardy’s own area, and he managed to prove them himself,

though with a good deal more trouble than I had expected. . . . The formulae 110-113 are on a different level and obviously both difficult and deep. . . . I had never seen anything the least like them before. A single look at them is enough to show that they could only be written down by a mathematician of the highest class. They must be true because, if they were not true, no one would have had the imagination to invent them. (Hardy, cited in J. R. Newman, 1956)

Suppose that Gauss or Ramanujan had been born with a healthy MZ twin who was spirited away to be reared by some country parson in Oxfordshire. Barring cholera or other accident, is it not likely that the parson’s surname too would now be immortal? Ramanujan died young without offspring; his parents and one brother apparently were unexceptional. Although Gauss provided

rich stimulation and opportunity for his six offspring (by two different and highly cultivated wives), none of them distinguished themselves.<sup>2</sup> But if the genius of these men was prefigured in their genes, why was it never manifested elsewhere in their lineage? The answer is, we think, that genius consists of unique configurations of attributes that cannot be transmitted in half helpings.

Michael Faraday, the premier experimental scientist of his generation, was the self-taught son of a humble blacksmith (Thomas, 1991). Knight (1985) referred to Faraday’s “curious mixture, or perhaps we should say compound, of humility and pride” (p. 35); biographers of people of genius often allude in this way to interactions or configurations of their subjects’ attributes. We know that Shakespeare, too, came from undistinguished stock, that this foremost wordsmith in our history had numerous siblings and several children, none of whom left any trace—or any word—behind them (Parrott, 1938). An American genius, Benjamin Franklin, was one of a large family and sired two children of his own, all of them members of the common generality of humankind (Garfield, 1982). The configularity of genius is dramatically illustrated in the life’s work of another extraordinary American, Gutzon Borglum, the sculptor, engineer, inventor, and entrepreneur who carved Mount Rushmore (Shaff, 1985). However one evaluates the aesthetic or ecological impact of transforming a mountain into a frieze of presidential heads, this prodigious monument will survive the millennia because of the configuration of prodigious talents, each of them essential to the project, that were combined in this singular individual. One of the luminaries of twentieth-century science, John von Neumann, was capable of such extraordinary intellectual feats that some of his colleagues were led to suggest that von Neumann’s brain “might be an emergent organ, of a different order of complexity than those of ordinary mortals” (Campbell, 1988, p. 103.) Genius of this caliber seems to be not just an abundance of one or several components such as IQ but rather a harmony of attributes, a compound rather than merely a mixture.

#### **Some More Mundane Examples**

**Electrodermal nonresponding.** Some psychiatric patients, during remission of their symptoms when they are relatively normal, are EDR nonresponders in the habituation situation referred to above; they do not react electrodermally even to the first loud tones (Bernstein et al., 1988). About 15% of the individuals in our sample of normal twins (Lykken et al., 1988) also were EDR nonresponders. None of them had psychiatric histories, but we think it possible that these people might have had the genetic “talent” for one of the major psychiatric disorders (Iacono, 1982, 1985; Iacono et al., 1983). At least one member of

<sup>2</sup> Gauss’s second son, Eugene, emigrated to the United States in 1830, enlisted in the army, and later went into business in Missouri. Eugene is said to have had some of his father’s gift for languages and the ability to perform prodigious arithmetic calculations, which he did for recreation after his sight had failed him in old age.

16 of the 79 MZ pairs was a nonresponder, and 12 of their 16 co-twins (75%) were nonresponders also. Eight of the smaller group of 42 DZ pairs contained a nonresponder, but only one pair (13%) was concordant (Lykken et al., 1988).

*Striped flight and blotched belligerence.* It is well known that morphological and behavioral traits are often correlated across related species. For example, in snakes, species whose coats are longitudinally striped “tend to be more active, wide-foraging, and flee when threatened, whereas species with broken color patterns (blotches or crossbands) are more secretive and rely on crypsis or aggression as their primary defense” (Brodie, 1989, p. 542). This same heterogeneity in color pattern and behavior has also been observed within a single species, the Northwest garter snake, and Brodie has shown that vulnerability to predation is a configurational function of color pattern together with the tendency to freeze or flee. “It is more difficult for the vertebrate eye to detect motion or judge the speed of a moving stripe than a moving heterogeneous pattern, so that flight may be a more effective antipredator behavior for striped snakes than for blotched ones” (Brodie, p. 544). Among most snake species, configurations of coat markings and behavior tendencies that yield higher vulnerability to predators have disappeared through natural selection; in the garter snake, two different configurations, two mutually exclusive emergenic traits—what Tooby and Cosmides (1990) call “heritable alternative strategies”—have proved adaptive and have survived. Note that such heritable alternative configurations, although emergenic, may tend to run in families.

### The Structure of Qualitative Emergenic Traits

Li (1987) has examined in detail a *multiple homozygosis* model for qualitative emergenic traits. Li assumes as an example a trait that is produced by a configuration of two recessive alleles in each of  $k = 5$  independently segregating loci, each allele having a moderate gene frequency of 0.20. The frequency in the population of such a trait would be approximately  $10^{-7}$ , so this is a truly rare anomaly, talent, or idiosyncrasy. A mating with one affected parent has only about 3 chances in 10,000 of producing an affected child, whereas the probability of concordance in a pair of DZ twins with one affected **proband** is less than 1%. As Li points out, any of the  $3^5 = 243$  different genotypic configurations possible with five loci might be the one that effects the trait in question and, moreover, it is biologically plausible that other closely related genotypes (e.g., **aaBbccddee** as well as **aabbccdde**) might effect an approximation of the emergenic trait, “This situation is analogous to that of man-made growth hormones or insulin molecules, which, though not perfect, may still have some biological activities” (Li, 1987, p. 523).

A relatively simple example of multiple homozygosis is dactylaplasia, the absence of phalangeal bones in the middle digits of each foot, which is due (at least in mice) to a mutant autosomal dominant gene, **M**, that is **epistatically** inhibited by a dominant gene, **X**, at another locus

(Chai, 1981). Although all MZ twins will be concordant for this trait, concordance among sib pairs will be only 12.5%, if the frequency of the **X** gene,  $P(X)$ , equals 0.5, and only 0.5% if  $P(X) = 0.9$ . Because it is configurational, dactylaplasia is an emergenic trait; because it is strongly genetic but only weakly familial, it is a trait that might not be seen to be genetic had one not observed it in MZ twins or inbred strains.

### Threshold Traits

A threshold trait can be defined as a qualitative phenotype that is observed when the individual's susceptibility or risk exceeds some threshold value. The threshold is normally considered to be determined by the environment (or even by convention, as in psychiatric diagnosis), whereas the metrical risk is at least partly heritable. Fitting threshold models to concordance data for various kinship pairings has been popular since Falconer (1960). A number of qualitative psychopathological traits that are definitely familial, traits like schizophrenia and antisocial personality, do not seem to fit any simple Mendelian model. For example, bipolar affective disorder is approximately 70% concordant in MZ twins but less than 15% in DZs and other sib pairs (Novitski, 1982, p. 377). When such a phenotype can be fitted to the Falconer model, it is commonly assumed that the underlying genetic mechanism is polygenic-additive.

Chai (1981) pointed out, however, that threshold models can be (and commonly are) fitted to the statistics of such congenital malformations as dactylaplasia, where the model is now known to be wrong. He argued that the threshold model “is not a useful concept since it cannot be experimentally disproved ... [and it] has practically frozen research in congenital malformations ever since the concept was adopted” (p. 237). (Because Chai himself experimentally disproved the threshold model in the case of dactylaplasia, we interpret his criticism to be that the threshold model too easily appears to fit cases where it in fact is false.) The dactylaplasia example illustrates the possibility that other qualitative traits for which the MZ concordance is much higher than the DZ value, including dysfunctional traits like schizophrenia and antisocial personality, may in fact be emergenic.

### Schizophrenia

Manfred Bleuler's view was that “hereditary dispositions to schizophrenia consist in *disharmonic* tendencies for personality development” (quoted in Rosenthal & Kety, 1968, p. 12, italics added). *Harmony* is a configurational concept; in suggesting that the schizophrenic diathesis involves a dysfunctional or disrupted configuration, Bleuler seems to be implying an emergenic model. The fact that the concordance for schizophrenia (as for bipolar affective psychosis) is much higher in MZ twins (44%–58%) than in DZ twins or siblings (8%–14%; Gottesman & Shields, 1982; Rosenthal, 1970) tends to encourage this view. But schizophrenia *is* familial. The incidence even in second-degree relatives is clearly higher than in the general population. Therefore, if this trait is configurational, the number

of independent loci involved must be no greater than two or three (configurations of four or more loci yield non-familial traits unless the gene frequencies are very high); We have made a preliminary study of two-locus models but have not found adequate fits to the available data on the morbid risk among relatives of probands. A dominant-recessive model, however, with the right choice of gene frequencies, penetrance, and fertility assumptions, comes close enough so that we feel confident that a similar three-locus model, with its still greater degrees of freedom, could produce an excellent fit. The protean character of such models, of course, detracts from their value; Chai did not merely show that a two-locus model *could fit* dactylaplasia but rather that a particular two-locus model was correct. Because one cannot do back-cross experiments with human subjects, showing that a three-locus emergenic model is "correct" for schizophrenia, if possibly it is, will be difficult; but, like the polygenic threshold model and the idea that "schizophrenia" conflates several etiologically distinct disorders, the emergenic model remains a possibility.

### *The Game of Life*

The educational pastime known as poker provides a useful analogy that may help clarify the idea of emergence. At conception, each of us received a very large number of "cards" containing a very large number of potential "hands," probably more than one could hope to play out in the course of the typical life. In one form of poker, each player is dealt seven cards and then must select three to be passed to his or her neighbor on the right. This game is interesting for configurational reasons; the cards you receive from the person on your left were of little value in the context of his or her other cards, but they just might be exactly what you need to create a winning hand.

At conception, each of us received an approximately random half of the cards dealt out originally to each of our parents. Your tall mother held four queens, and she passed three of them along to you. Combining them (additively) with a queen from the paternal line, you can stand as tall as Mom. Your handsome father held a royal flush in hearts. Your half of his cards included the king, queen, and jack of hearts, but your mirror tells you that a three-card approximation of a royal flush looks merely "interesting," not handsome. The exciting thing about emergence is that you *might* receive the 10 and king of spades from Dad, and the jack, queen, and ace of spades from Mom, cards that had never counted for much in either family tree but whose combination in you might produce a Ramanujan, a new Olympic record-or a True Crime miniseries for television.

### **Summary and Conclusion**

Species-specific traits are assuredly produced by configurations of monomorphic polygenes, interacting with each other and with the environment in roughly the same sense that specialized construction workers interact with the supply stocks and with the elaborating structure. It is plausible to assume that some polymorphic traits of psy-

chological interest, similarly, are produced by configurations of polymorphic genes, similarly interacting with the environment both embryologically and during subsequent development. Such configurational polymorphisms can be labeled *emergenetic* traits. This configurational emergenic model provides a possible explanation of those metrical traits for which MZ twins are substantially more than twice as similar as DZ twins and other first-degree relatives. Examples of putatively emergenic metrical traits include extraversion, EEG alpha frequency, electrodermal habituation, certain recreational and occupational interests, and facial and vocal beauty. Other interesting possibilities, for which no relevant data exist to our knowledge, include complex competencies such as leadership, selling ability, being an effective teacher or parent, and so on.

Taxonic or qualitative traits that show high concordance in MZ twins may also be emergenic. These may include developmental anomalies, idiosyncrasies of taste and style, various psychopathological syndromes, and some examples of human genius. One frequent (but not inevitable) feature of an emergenic trait is that it may tend not to run in families. This is because traits resulting from rare configurations of polygenes, or from unusual configurations of component traits, are unlikely to be passed on intact from parent to offspring. Genetic traits that do not run in families are unlikely to be seen to be genetic (i.e., to have an important part of their variance associated with genetic variance) unless one is studying monozygotic twins.

We conjecture that the most interesting emergenic psychological traits will turn out to be taxonic or qualitative. There is a strong tradition in psychology to eschew categorical in favor of dimensional thinking, a tradition in psychometrics that runs unbroken from **Spearman** to Eysenck (1986). But taxonomy, the classification of types of entities, is an integral part of all of the natural sciences from biology to astronomy. Meehl(1992) made a strong case for the existence of **taxa** not only in psychopathology but also in relation to those individual differences that we regard as normal. To the extent that some of these **taxa** (for the discovery of which Meehl provided powerful statistical tools) will turn out to be genetically influenced, we would expect them to be also emergenic.

The suggestion that genius may be emergenic should be understood to include what is called evil genius. Even those who tend to reject the Great Man theory of history find it hard to defend the proposition that the history of Europe in this century would not have been vastly different if Adolf Hitler had been killed by an English bullet in 1918. If Hitler had been one of 10 brothers, 9 of whom survived the First World War, it is unlikely that any one of the brothers would have become chancellor of the Third Reich. But if Hitler had left behind an MZ twin, who then would be prepared to deny the possibility that events might have developed much as, in fact, they did?

It is worth considering whether the competencies listed above as metrical traits might not be more accurately classified as qualitative traits. We obviously can

rank salespeople, teachers, scientists, psychotherapists, or leaders on continua of competence, but they are already self-selected members of what may be taxonomic groupings. If 1,000 people at random are put to work selling used cars or commanding military units, psychoanalyzing or behavior modifying, doing research or teaching sixth-grade civics, we would find a J-curve and, quite possibly, a bimodal distribution of competence: just a few good salespeople (some better than others), just a few charismatic leaders, a few born teachers, and a handful of truly effective therapists. Even compared with other scientists, some 5% publish 50% of the papers (Price, 1962). Suppose we could truly assess parenting, not merely measuring effort or dedication but *effectiveness*—given the raw material with which a parent had to work, how good was his or her product (measured by some reasonable standard of parental success) in comparison with an average parent working with the same raw material (e.g., the MZA co-twin)? Might not our evaluations of parenting ability also be bimodal, with just a few gifted parents and the majority merely providers, relatively ineffectual in actually shaping in some intended way?

It seems hardly speculative to contend that great competence in any area, competence for good or for ill, is likely to involve a *configuration* rather than a mere aggregation of component traits. In their discussion of exceptional performance, Walberg, Strykowski, Rouai, and Hung (1984) concluded that the J-curve of performance output or impact results from many factors interacting in a multiplicative, rather than an additive, manner. Because there is much evidence that a substantial portion of the variance in nearly all human psychological traits is genetic variance (in the broad sense of nature *via* nurture), then it seems likely that great competence is also emergenic.

The rare occurrence of extraordinarily adaptive configurations (e.g., Secretariats or other hopeful monsters) among other species will have lasting consequences only when chance conspires to produce a critical mass of *traited* individuals able to found a new subspecies. For our humankind, however, culture provides a mechanism through which individuals of extraordinary competence, although unable to pass on their configured talents to succeeding generations, can nonetheless leave behind works of art or invention or political upheaval that do have lasting consequences.

Finally, the concept of emergence has obvious, albeit speculative, evolutionary implications. Coldschmidt's (1940) hopeful monster proposal could be interpreted as a conjecture that *saltation* or even speciation is sometimes a consequence of a new genetic configuration with emergent properties. Although the evidence is somewhat indirect, it is now widely believed that the human monomorphic genome differs from that of some of the great apes to the extent of only a few percent of its constituent genes. If the book of instructions that produces a human being shares nearly all of its pages with the book that yields a chimpanzee, then is it not likely that the books must differ in some other way, perhaps in the sequence

(i.e., configuration) in which many of the pages are arranged? We propose that emergenic differences exist within all species of living things, including *Homo sapiens*, and that such configurational diversity has contributed to the evolution of diversity both within and among species.

## REFERENCES

- Abrams, S. (1986). Disposition and environment. *The Psychoanalytic Study of the Child*, 41, 41–60.
- Anderson, N. H. & Shanteau, J. (1977). Weak inference with linear models. *Psychological Bulletin*, 64, 115–117.
- Anthony, D., Telegin, D. V., & Brown, D. (1991). The origins of horseback riding. *Scientific American*, 265, 94–100.
- Bernstein, A. S., Riedel, J., Graae, F., Seidmen, D., Steele, H., Connolly, J., & Lubowsky, J. (1988). Schizophrenia is associated with altered orienting activity: depression with electrodermal (cholinergic?) deficit and normal orienting response. *Journal of Abnormal Psychology*, 97, 3–12.
- Block, J. (1965). *The challenge of response sets*. New York: Appleton-Century-Crofts.
- Borwein, J. M., & Borwein, P. B. (1988). Ramanujan and pi. *Scientific American*, 258, 112–117.
- Bouchard, T. J., Jr., Lykken, D. T., McGue, M., Segal, N. L., & Tellegen, A. (1990). Sources of human psychological differences: The Minnesota Study of Twins Reared Apart. *Science*, 250, 223–228.
- Buhler, W. K. (1981). *Gauss: A biographical study*. Berlin: Springer-Verlag.
- Brodie, E. D., III. (1989). Genetic correlations between morphology and antipredator behavior in natural populations of the garter snake *Thamnophis ordinoides*. *Nature*, 342, 542–543.
- Campbell, J. (1988). *Grammatical man*. New York: Simon & Schuster.
- Cattell, R. B. (1956). Second-order personality factors in the questionnaire realm. *Journal of Consulting Psychology*, 20, 411–418.
- Cattell, R. B. (1982). *The inheritance of personality and ability*. San Diego, CA: Academic Press.
- Cavalli-Sforza, L. L., & Bodmer, W. F. (1971). *The genetics of human populations*. New York: Freeman.
- Chai, C. K. (1981). Dactylaplasia in mice. *The Journal of Heredity*, 72, 234–237.
- Cunningham, P. (1991). The genetics of thoroughbred horses. *Scientific American*, 265, 92–98.
- Dawkins, R. (1982a). *The blind watchmaker*. Essex, England: Longman.
- Dawkins, R. (1982b). *The extended phenotype*. Oxford, England: Oxford University Press.
- Durant, W., & Durant, A. (1967). *Rousseau and revolution*. New York: Simon & Schuster.
- Dunnington, G. W. (1955). *Curt Friedrich Gauss: Titan of science*. New York: Hafner.
- Eaves, L. J. (1976). The effect of cultural transmission on continuous variation. *Heredity*, 37, 41–57.
- Eaves, L. J. (1987). Dominance alone is not enough. *Behavior Genetics*, 18, 27–34.
- Eysenck, H. J. (1952). *The scientific study of personality*. London: Kegan Paul, Trench, & Trubner.
- Eysenck, H. J. (1986). A critique of contemporary classification and diagnosis. In T. Millon & G. L. Klerman (Eds.), *Contemporary directions in psychopathology* (pp. 73–78). New York: Guilford Press.
- Falconer, D. S. (1960). *Introduction to quantitative genetics*. New York: Ronald Press.
- Farber, S. L. (1981). *Identical twins reared apart: A reanalysis*. New York: Basic Books.
- Fedotchev, A. I., Bonda, A. T., & Konovalov, V. F. (1990). Stability of resonance EEG reactions to flickering light in humans. *International Journal of Psychophysiology*, 9, 189–194.
- Galton, F. (1869). *Hereditary genius*. London: Macmillan.
- Garfield, E. (1982). Benjamin Franklin: Philadelphia's scientist extraordinaire. *Current Contents*, 40, 5–12.
- Goldschmidt, R. B. (1940). *The material basis of evolution*. New Haven, CT: Yale University Press.

- Gottesman, I. I., & Shields, J. (1982). *Schizophrenia: The epigenetic puzzle*. Cambridge, England: University of Cambridge Press.
- Grayson, D. A. (1989). Twins reared together: Minimizing shared environmental effects. *Behavior Genetics*, *19*, 593-604.
- Heath, A. C., Martin, B. G., Eaves, L. J., & Loesch, D. (1984). Evidence for polygenic epistatic interactions in man. *Genetics*, *106*, 719-727.
- Iacono, W. G. (1982). Bilateral electrodermal habituation/dishabituation and resting EEG in remitted schizophrenics. *Journal of Nervous and Mental Disease*, *170*, 91-101.
- Iacono, W. G. (1985). Psychophysiological markers of psychopathology: A review. *Cunudiun Psychology*, *26*, 96-112.
- Iacono, W. G., Lykken, D. T., Peloquin, L. J., Lumry, A. E., Valentine, R. H., & Tuason, V. (1983). Electrodermal activity in euthymic patients with affective disorders: A possible marker of depression. *Archives of General Psychiatry*, *40*, 557-565.
- Jinks, J. L., & Fulker, D. W. (1970). Comparison of the biometrical, MAVA, and classical approaches to the analysis of human behavior. *Psychological Bulletin*, *73*, 311-349.
- Juel-Nielson, N. (1965). Individual and environment: A psychiatric and psychological investigation of monozygous twins raised apart. *Acta Psychiatrica et Neurologica Scandinavica (Suppl.)*, *183*.
- Knight, D. M. (1985). Davey and Farraday: Fathers and sons. In D. Gooding & F. A. J. L. James (Eds.), *Furuday rediscovered* (pp. 33-50). New York: Stockton.
- Kolata, G. (1987). Remembering a "magical genius." *Science*, *236*, 1519-1521.
- Kroeber, A. H. (1944). *Configurations of culture growth*. Berkeley: University of California Press.
- Lewontin, R. C. (1967). An estimate of average heterozygosity in man. *American Journal of Human Genetics*, *19*, 681-685.
- Li, C. C. (1987). A genetical model for emergence. *American Journal of Human Genetics*, *41*, 517-523.
- Loehlin, J. C., & Nichols, R. C. (1976). *Heredity, environment, and personality*. Austin: University of Texas Press.
- Lykken, D. T. (1982). Research with twins: The concept of emergence. *Psychophysiology*, *19*, 361-373.
- Lykken, D. T. (1991). What's wrong with psychology anyway? In D. Cicchetti & W. M. Grove (Eds.), *Thinking clearly about psychology* (Vol. I, pp. 3-39). Minneapolis: University of Minnesota Press.
- Lykken, D. T., Bouchard, T. J., McGue, M., & Tellegen, A. (1990). The Minnesota Twin Registry: Some initial findings. *Acta Geneticae Medicae et Gemmellologiae*, *39*, 35-70.
- Lykken, D. T., Bouchard, T. J., McGue, M., & Tellegen, A. (1992a). *The heritability of interests: A twin study*. Manuscript submitted for publication.
- Lykken, D. T., Bouchard, T. J., McGue, M., & Tellegen, A. (1992b). *Nature via nurture: The implications of recent twin research*. Manuscript submitted for publication.
- Lykken, D. T., Iacono, W. G., Haroian, K., McGue, M., & Bouchard, T. J. (1988). Habituation of the EDR to strong stimuli: A twin study. *Psychophysiology*, *25*, 4-16.
- Lykken, D. T., Tellegen, A., & Iacono, W. G. (1982). EEG spectra in twins: Evidence for a neglected mechanism of genetic determination. *Physiological Psychology*, *10*, 60-65.
- Lykken, D. T., Tellegen, A., & Thorkelson, K. (1974). Genetic determination of EEG frequency spectra. *Biological Psychology*, *1*, 245-259.
- McGue, M., Bacon, S., & Lykken, D. T. (in press). Personality stability and change in early adulthood: A behavioral genetic analysis. *Developmental Psychology*.
- Meehl, P. E. (1992). Factors and taxa, traits and types, differences of degree and differences in kind. *Journal of Personality*, *60*, 117-174.
- Murphy, E. A. (1979). Quantitative genetics: A critique. *Social Biology*, *26*, 126-141.
- Newman, H. H., Freeman, F. N., & Holzinger, K. J. (1937). *Twins: A study of heredity and environment*. Chicago: University of Chicago Press.
- Newman, J. R. (1956). Srinivasa Ramanujan. In Newman, J. R. (Ed.), *The world of mathematics* (Vol. I, pp. 368-380). New York: Simon & Schuster.
- Novitski, E. (1982). *Human genetics* (2nd ed.). New York: Macmillan.
- Parrott, T. M. (1938). *Shakespeare*. New York: Scribner.
- Pederson, N. L., Plomin, R., McClearn, G. E., & Friberg, L. (1988). Neuroticism, extraversion, and related traits in adult twins reared apart and reared together. *Journal of Personality and Social Psychology*, *55*, 950-957.
- Plomin, R., & Daniels, D. (1987). Why are children in the same family so different from one another? *Behavioral and Brain Sciences*, *10*, 1-16.
- Price, D. J. (1962). The exponential curve of science. In B. Barber & W. Hirsch (Eds.), *The sociology of science* (pp. 112-131). New York: Free Press.
- Propping, P. (1977). Genetic control of ethanol action on the central nervous system. *Human Genetics*, *35*, 309-334.
- Rosenthal, D. (1970). *Genetic theory and abnormal behavior*. New York: McGraw-Hill.
- Rosenthal, D., & Kety, S. S. (Eds.). (1968). *The transmission of schizophrenia*. Oxford, England: Pergamon Press.
- Shaff, H. (1985). *Six wars at a time: The life and times of Gutzon Borghum*. Darien, CT: Permelia.
- Shields, J. (1962). *Monozygotic twins brought up apart and brought up together*. London: Oxford University Press.
- Simonton, D. K. (1988). *Scientific genius: A psychology of science*. Cambridge, England: Cambridge University Press.
- Stassen, H. H., Lykken, D. T., Propping, P., & Bomben, G. (1988). Genetic determination of the human EEG. *Human Genetics*, *80*, 165-142.
- Stearns, S., & VanderWoude, A. (1991). *Musical talent among first-degree relatives of university students majoring, or not majoring, in instrumental or vocal music*. Unpublished student research report, University of Minnesota, Department of Psychology, Minneapolis.
- Tellegen, A., Lykken, D. T., Bouchard, T. J., Wilcox, K., Segal, N., & Rich, S. (1988). Personality similarity in twins reared apart and together. *Journal of Personality and Social Psychology*, *54*, 1031-1039.
- Tellegen, A., & Waller, N. (in press). Exploring personality through test construction: Development of the Multidimensional Personality Questionnaire. In S. R. Briggs & J. M. Cleek (Eds.), *Personality measures: Development and evaluation* (Vol. I). Minneapolis: University of Minnesota Press.
- Thomas, J. M. (1991). *Michael Furuday and the Royal Institution: The genius of man and place*. New York: American Institute of Physics.
- Tooby, J., & Cosmides, L. (1990). On the universality of human nature and the uniqueness of the individual: The role of genetics and adaptation. *Journal of Personality*, *58*, 17-68.
- Walberg, H. J., Strykowski, B. F., Rouai, E., & Hung, S. S. (1984). Exceptional performance. *Review of Educational Research*, *54*, 87-112.
- Waller, N., Lykken, D. T., & Tellegen, A. (in press). Occupational interests, leisure time interests, and personality: Three domains or one? In R. Dawes & D. Lubinsky (Eds.), *Assessing individual differences in human behavior: New methods, concepts and findings*. Minneapolis: University of Minnesota Press.