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Research With Twins: The Concept of Emergenesis

DAVID T. LYKKEN
University of Minnesota

ABSTRACT

Preliminary findings from an on-going study of monozygotic twins reared apart (MZA) and data from a larger sample of twins reared together (MZT and DZT), indicate a surprisingly strong influence of genetic variation on aptitudes, psychophysiological characteristics, personality traits and even dimensions of attitude and interest. For some of these variables, MZT and MZA twins show high intra-class correlations while DZT twins are no more similar than pairs of unrelated persons. It is suggested that such traits are "emergenic," i.e., that they are determined by the interaction-rather than the sum-of genetic influences. Emergenic traits, although perhaps strongly genetic, will not tend to run in families and for this reason have been neglected by students of behavior genetics. For this and several other listed reasons, wider use of twins in psychological research is strongly recommended.

DESCRIPTORS: Twins, Behavior genetics, Emergenesis, Range correction, EEG spectra.

Almost any experiment that one might think of doing with human subjects will be more interesting and yield more valuable results if one does it with twins. Many people think of twin research as being exclusively concerned with estimating the heritability of traits but this is a mistake. Indeed, the classical twin method, in which heritability (H) is estimated from the difference in similarity of monozygotic (MZ) and dizygotic (DZ) twins reared together ($H = 2[R_{mz} - R_{dz}]$), is so inefficient that impracticably large samples are required to yield stable estimates which, even then, depend upon dubious assumptions (Loehlin & Nichols, 1976; Lykken, Geisser, & Tellegen, Note 1). Here are several better reasons for doing one's research with twins:

(1) Twins are plentiful and easily recruited as experimental subjects. There are perhaps 2 million sets of twins in the United States, more than the total supply of college sophomores. A good time for recruiting young adult twins who are demographically representative is when they are seniors in high school and at least 20,000 pairs of same-sex twins graduate from U.S. high schools every year.

(2) Twins are obviously special in some ways but, with respect to ethnic origin, socio-economic level, educational background, and similar variables, twins are probably more representative of the general population than any other group to which psychologists normally have easy access.

(3) This representativeness is even more true of the families of twins. I have collected personality questionnaire data from some 400 middle-aged adults, people from rural, small town and urban areas, with educations ranging from grade school through advanced degrees. How can one recruit such a sample?-by recruiting twins. The parents of these twins are truly representative of their age group, a cohort that would be likely to rebuff a psychologist asking personal questions. But the parents of twins find it natural that researchers should be interested in their offspring and they readily accept that one might also want data from the parents as well, for comparison purposes.

(4) Twin data are invaluable for selecting useful variables or in choosing among alternative methods or units of measurement. One of the reasons why psychological research so often fails to replicate is because our measures are full of error variance or fail to carve Nature at her joints. But any measure that shows high within-pair correlation among MZ twins

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Address requests for reprints to: David T. Lykken, Psychiatry Research Unit, Box 392, Mayo Hospital, University of Minnesota, Minneapolis, MN 55455.

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deserves to be treated with respect. If X and Y are alternate ways of measuring some variable of interest and if X yields an MZ correlation appreciably higher than Y does, then X is almost certainly the better method. Whatever one's views may be on the nature:nuture question, monozygotic twins can be thought of as ***parallel forms of the same individual*** and this is extremely handy for the researcher.

(5) Associated with this same point is the method of co-twin control which provides enhanced experimental power. It is difficult to find a reliable measure of anything that correlates less than .50 within-pairs of MZ twins. Using one twin from each pair for the experimental group and the other for the control group provides a test of one's hypothesis that is as powerful as an experiment employing twice as many pairs of singletons. If the MZ correlation is .75, the co-twin control is four times as powerful as using singletons.

(6) If one treats one's subjects properly, taking pains to make their tirst visit seem interesting and worthwhile, and keeps them on a mailing list with subsequent contacts, newsletters, and the like to maintain interest, then it will be possible to bring many of them back repeatedly over the years to participate in additional experiments. This is useful not only for longitudinal research but as a method of enhancing each subsequent experiment with the information previously gathered on these same individuals. One can of course do this with singletons but it seems to work especially well with twins. Some of the pairs that we first recruited more than 10 years ago have returned several times for various studies and their commitment to our enterprise seems to grow with time.

For all of the above reasons, I have been working with adult twins since 1970 with numerous students and colleagues, most recently F. Gabbay, K. Haroian, W. Iacono, L. Peloquin, and A. Tellegen. In 1979, T. J. Bouchard, Jr. persuaded me to join with him, Leonard Heston, and others on a study of twins who were separated as infants and reared apart. Due to Bouchard's zeal and efficiency, and to the extensive publicity this work has received, publicity which has been essential to our success in recruitment, this on-going study is already one of the largest and certainly the most extensive ever done with reunited twins. It may also be the last research of its kind since adoption agencies, at least in the West, have ceased to separate twins as was commonly done in years past. Before we are finished, we hope to study 100 pairs of monozygotic twins reared apart (MZA twins) along with 50 pairs of DZAs or same-sex siblings reared apart.

As of November, 1981, we had brought a total of 30 pairs of MZA and 9 pairs of DZA twins to Minneapolis, together with their spouses when possible, for a full week of study and testing. Newman, Freeman, and Holzinger's classic study (1937) was based on only 19 pairs while Juel-Nielsen's (1965) consisted of just 12 pairs, so our sample is already respectable in size and it is unparallaled in quality. About half of our pairs either met for the tirst time, as adults, when they came to Minnesota or had that first reunion just weeks or a few months previously. As shown in Table 1, the mean age at separation for the three large previous studies, including the one reported by James Shields (1962), was 17 months; our twins on the average were separated at 4 months. The average age at reunion for the prior studies was only 12 years while it averages 24 years for our sample. But the unique feature of this study is the intensity and extensivity of coverage. One of our assistants estimated that, during their grueling week with us, each twin is asked a total of some 15,000 questions, about 4,000 of them in the form of self-report questionnaires and inventories. By the use of overlapping measures, we are attempting to focus on factors or constructs rather than just test scores.

I shall discuss in this paper an idea that grew out of our earlier twin research and has been greatly reinforced by our experience so far with twins reared

TABLE 1

The four major studies of monozygotic twins reared apart

studies	Age When studied	Age at Separation	Age at Reunion	Number of MZ Pairs
Newman et al. (1937)	26.1	1.6	12.5	19
Shields (1962)	38.8	1.4	11.0	44
Juel-Nielsen (1965)	51.4	1.5	15.9	12
Minnesota Study (1981)'	36.1	0.3	23.9	30

The on-going Minnesota Study, involving a full week of testing, has so far obtained a sample of twins who were separated earlier and reunited later than in previous work. Because dizygotic twins are also accepted for study, there is no selection for similarity among the MZA twins.

Three pairs of monozygotic twins separated as infants and reared apart. These identical triplets discovered each other by accident a few months before this picture was taken.

apart, an idea that I think is **provocative** and possibly important. The evidence I shall present includes measures made on twins of EEG spectra, skin conductance responses in an habituation paradigm, and also measures of intellectual ability, personality traits, and even recreational interests. The concept that I think this evidence supports has to do with human genetics and concerns a phenomenon that we call "emergenesis."

The Concept of Emergenesis

Geneticists have concentrated on two basic mechanisms of genetic transmission. Medical geneticists tend to focus on the Mendelian mechanism in which the occurrence of a trait depends on the presence or absence of a particular allele at a specific gene locus. Behavior geneticists, on the other hand, have paid most attention to the Galtonian mechanism of polygenic transmission in which the value of some metrical trait, like stature or maze brightness, is thought to be determined by the additive action of a number of genes at different loci. Both mechanisms are sometimes complicated by two types of simple interaction. One of these, called dominance, occurs when the expression of a gene at one locus is modulated by another gene-a dominant allele-at the corresponding locus of the paired chromosome. The other form of interaction, called *epistasis*, is a kind of dominance relationship between two genes at different loci.

There is a third type of genetic mechanism that has been largely neglected, a mechanism that involves a more general type of gene interaction. This is a polygenic mechanism in which the gene effects combine configurally rather than additively. Suppose, for example, that the effect we are looking for involves the synthesis of a certain protein molecule. This hypothetical protein might be assembled from polypeptides that are coded for by 12 genes and each of these 12 genes is on a different chromosome so that they all segregate independently. Suppose, finally, that these are not 'basic blueprint' genes that everybody has but rather that their frequency of occurrence in the population is around, say, 25%. Now if I happen to have acquired all 12 genes in the great lottery that takes place at conception, then I will have the protein we are looking for. My monozygotic twin, if I have one, will also show this trait since he has the same genes I do. But there are fewer than 3 chances in 10,000 that I will manage to pass on all 12 needed genes to my child. Even if my wife and I both possess this special protein, but are both heterozygous for each of the 12 genes, then there would still be fewer than 4 chances in 100 that a child of *ours* would be protein-positive.

It is generally accepted that most of the basic characteristics of the organism are in fact determined by such interactions among the monomorphic genes that are shared by all normal members of the species (e.g. Stem, 1973, pp. 68-70). A hand is' not constructed by the additive combination of a lot of little "hand genes," each contributing its mite. If it were, then if through mutation in a parent you lacked one or more of the hand genes, you would still have a miniature version of a standard-model hand. Instead, of course, the genetic mechanism for making hands is complex and configural and if you are lacking just one of the structural genes, your hand will be qualitatively different from that specified in the species plan. Indeed, many Mendelian traits can be seen to depend upon this standard interactive process; the normal configuration is broken by the absence of some key-allele and the lack of that one gene produces an effect that is devastating precisely because, in a configuration, every component is a keystone element. What I am suggesting now, however, is that this *configural* mode of determining phenotypic consequences is not only standard for the monomorphic genes that we all share but may be a common mechanism also for those polymorphic alleles that contribute to the diversity of genotypes within a species and, thus, to individual differences in the phenotype.

Quantitative geneticists refer to this interactive mechanism in the first chapter of their textbooks but tend to neglect it thereafter. Some authorities explicitly assume that such effects "are unlikely to have such important consequences as other possible inadequacies of the model, such as the assumption of random mating" (Jinks & Fulker, 1970, p. 318). Others acknowledge that this mechanism may account for a significant proportion of the variance but argue that, "it is difficult, if not impossible, in human populations to collect the information necessary for its estimation" (Cavalli-Sforza & Bodmer, 1971). They also have a name for this mechanism; they call it "epistasis" (Kempthorne, 1957). But the etymology is wrong for this purpose and "epistasis" already has a clear and different meaning. Therefore, we have invented a new term, the Greco-Latin hybrid "emergenesis," reflecting the idea that an emergenic trait is an emergent property of a configuration of several or many independent or partly-independent genes. And one of the interesting facts about such emergenic traits is that, while certainly genetic, ***they*** will not tend to run ***in families.***

I am not at home in molecular biology so it is fortunate that emergenesis has a parallel meaning at a more molar level. Consider, for example, the human voice. It is a fact about MZ twins that their speaking voices are easily confusible, strikingly similar in pitch and timbre to an extent almost never found in siblings or in dizygotic twins. Now the tonal qualities of the voice are largely determined by the shape and relative dimensions of the resonant cavities in the head and chest and by the size, musculature and innervation of the vocal cords. We can assume that variability in most of the relevant components is under strong genetic control so that identical twins will make their vocal music with nearly identical instruments. But we must also assume that the several components that contribute to the distinctive sound of a voice also vary independently of one another; they are not inherited as a package. And voice quality is clearly a configural phenomenon that depends upon the interaction-rather than the simple summation—of the components of the vocal apparatus. Resonance, for example, plays an important role and every electronics expert knows that resonance is an emergent property of a resonant circuit, a property that depends on the way in which the components of that circuit interact with one another. Someone once pointed out that, at conception, we are each dealt out a hand of playing cards (a very large hand) and that the value of any particular card in the great game-to-come depends substantially on which other cards you hold, on how that card fits the rest of the hand. This is the root idea of the concept of emergenesis.

I think some form of emergenesis must be invoked to explain how the union of a bricklayer and a peasant woman produced a Karl Frederich Gauss and also why Gauss's offspring showed virtually none of his mathematical talent (one son could do extensive arithmetic computations in his head but this was at best just a facet of the genius that made his father "the prince of mathematicians"). Our MZ twins reared apart have produced a long list of curious similarities which make me think along the same lines. One pair of our MZA twins discovered, at their reunion last year, that they were both in the habit of wearing seven rings. There is certainly no gene or set of genes devoted to "ringedness"; this may be only mere coincidence yet I am inclined to think of an emergenic explanation. Another pair, middle-aged when they first found each other, are both given to giggling; it was difficult to catch them in a photograph with both wearing a sober expression. No one in either of their adoptive families was similarly inclined. In the backyards of another pair there are circumarboreal benches which each twin planned and built before they learned of each other's existence. Another pair both had claustrophobia and would enter my experimental chamber only if the door was tied open. This same pair discovered, while they were in Minneapolis, that they both compulsively count things, the wheels on a bus, the rooms in a house, and so on. Before learning that they had a twin, both had formed the habit, when at the beach, of entering the water backwards and only up to the knees. Another pair had independently developed into raconteurs, each with a fund of barroom stories. Yet another pair both liked to sneeze on crowded elevators so as to enjoy the discomfiture of their neighbors. All these may be examples of nothing more than sheer coincidence; indeed at least an element of environmental coincidence must be invoked in many cases. But there are so many of these "coincidences" (I have listed only a few examples) and since none of the DZA twins so far have proffered anything like this in spite of being urged to search for similarities, it seems reasonable to suggest an alternative hypothesis.

I am inclined to think that most of these coincidences could be understood in terms of the interaction or confluence of independent traits, each of which *is* under genetic control. Having long-fingered, good-looking hands, a somewhat extraverted personality, an attraction to glitter and a taste for adornment, the ability to achieve enough material success to allow the purchase of jewelry—all these are presumably independent traits, each possibly subject to genetic influence, which might interact so as to incline the woman who possesses all of them to wear multiple rings. All men are not equally likely to decide to build a lawn seat circling a tree. You have to have an interest in, and a talent for, such carpentry to begin with and then the choice of this unusual kind of a lawn seat reflects a peculiarity of taste which also may owe something to the genome. The fact that they both had a backyard and a tree may illustrate the sort of environmental coincidence that is required to permit these emergenic similarities to occur. What traits of personality and temperament interact to produce a habitual giggler? What kind of a person would sneeze in a crowded elevator just to get a rise out of the other passengers? I don't really know but I suspect that some of the necessary attributes are genetically influenced. All these examples are heuristic at best, however, and we need to look for some real evidence that emergenesis actually plays a role in determining individual differences in human behavior.

How shall we recognize emergenic traits? First, of course, they will show concordance or strong similarity in MZ twins. But, second, they should show little or no similarity in first-degree relatives, including DZ twins. Twin researchers compute intra-class correlations as measures of within-pair similarity and they expect DZ twins to be at least half as similar as the MZ twins, for strongly heritable traits, or more than half as similar in the case of traits for which shared environmental influences are important. Stature and fingerprint ridgecount illustrate the pattern expected of polygenic additive traits as shown in Table 2. The chief determiner of birth weight, in contrast, is gestational age at parturition and this (essentially environmental) factor will be nearly the same for both members of a twin pair whether MZ or DZ. Therefore, the correlation of birth weight in DZ twins is nearly as high

Dizygotic twins may be no more alike than unrelated persons with respect to emergenic traits.

TABLE 2

Intra-class correlations on certain anthropometric variables for monozygotic and dizygotic twins reared together (MZT and DZT) and a small sample of MZ twins reared apart (MZA)

Anthropometric Variables	Correlations MZA (N = 30)	MZT (N = 274)	DZT (N = 146)	Ratios DZT/MZT
Ridgecount	.98	.96	.46	48%
Height	.94	.93	.50	56%
Weight	.51	.83	.43	52%
Birth Weight	.92	.90	.87	97%

Note.—On strongly heritable traits like fingerprint ridgecount, height, and weight, the DZ correlation is expected to equal about half the MZ correlation. For traits that are mainly determined by environmental effects, as birth weight is determined by gestational age, the DZ correlation equals more than half the MZ correlation.

in MZs. ***When the MZ twins are very similar but the DZ correlations are near zero,*** that is when there is reason to suspect that the trait is emergenic.

In what follows, I shall present evidence of emergenesis employing five different types of data gathered from various samples of adult MZ and DZ twins.

Brainwave Spectra

It has been known for a long time that MZ twins have very similar EEGs. We published evidence of this in 1974 (Lykken, Tellegen, & Thorkelson, 1974.) The magnitude spectra in Figure 1-A show the relative amount of activity from zero to 20 Hz in the resting, eyes-closed occipital EEG for 3 of the 39 MZ pairs that we studied. We expressed the within-pair differences using a coefficient that we called the spectrum difference ratio. T'he smooth curve in Figure 2-A shows the distribution of this ratio for some 7,000 unrelated pairs formed by pairing each subject with every other except his own twin. When this ratio is equal to 1.0 or less one can say that the twins are as much like each other as they are like themselves over time; about one-third of the MZ pairs had ratios of 1.0 or less and their mean ratio was very reliably smaller than the mean for unrelated pairs.

The curious thing about this 1974 study was that the 27 DZ pairs had EEG spectra that were frequently quite dissimilar. As can be seen in Figure 2-B, their spectrum difference ratios indicated that they were no more alike than pairs of unrelated persons. We thought this result was interesting enough to be worth replicating and, in 1980, we finally got around to doing that (Lykken, Tellegen, & Iacono, 1982). This was a "constructive" rep-

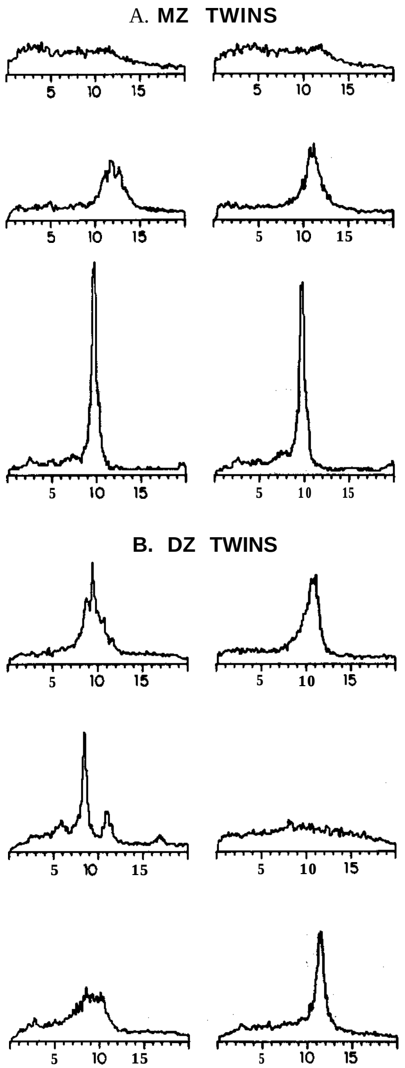

Figure 1. EEG spectra of adult twins reflecting the frequency composition, from 0 to 20 Hz, of a 3-min sample recorded from the occipital midline with respect to linked earlobes white the subject rested with eyes closed. Twin A is the first-born. These are magnitude spectra (the square-root of the power spectrum) which have been standardized to unit area. Most monozygotic (MZ) twins have spectra as similar as the 3 pairs illustrated in A; dyzgotic (DZ) twins, like the 3 pairs illustrated in **B**, produce spectra that are no more similar than those from pairs of unrelated persons.

lication in the sense that we changed a number of the experimental details in order to see how robust the findings were. We obtained the EEG from the top of the head instead of the back and from the left and right sides (C_3 and C_4) instead of the midline. This time we brought the twins to the lab separately on different days instead of running them simultaneously on the same day. The findings were just

TABLE 3

Intra-class correlations of five spectrum parameters in three samples of adult twins, including 25 pairs of monozygotic twins separated as infants and reared apart (MZA)

	Correlations			
Spectrum Parameters	MZA (N = 25)	**MZ (N=89)**	**DZ[1] (N=53)**	**Ratios DZ/MZ**
Delta	.90	.84	.30	36%
Theta	.76	.80	.43	54%
Alpha	.93	.86	.35	41%
Beta	.61	.72	.50	69%
Mean of above	.80	.81	.40	49%
Phi	.89	.81	.13	16%

Note.—The relative amount of activity in the four classic EEG bands (Delta, Theta, Alpha, Beta) shows on the average about half as much similarity in DZ twins as in MZ twins. Phi, the median frequency of the alpha activity, is negligibly correlated among DZ twins and thus appears to be an emergenic trait.

[1]DZ correlations were adjusted for reduced total variance in the DZ sample; see Lykken et al., 1982.

about identical with the 1974 findings (see Figure 2C, D). The MZ twins again were very similar within pairs while the DZ twins were again no more alike than unrelated persons.

We can get some insight into what is going on here if, rather than using the total root-mean-square differences between pairs of spectra, we look instead at the intra-class correlations for the parameters of these spectra (see Table 3). For example, the relative amount of activity in the alpha band, from 8 to 13 Hz, is one such parameter and its correlation for the combined group of MZ twins is .86 while, for the combined DZ sample, the alpha correlation is .35, not quite half as large. The MZ correlations for the four parameters Delta, Theta, Alpha and Beta average .81 and the mean DZ correlation for these four equals almost exactly 50% of this MZ correlation-just what we would expect for strongly heritable traits that obey the Galtonian additive model. The DZ twins are about half as similar as the MZ twins with respect to the amount of their EEG activity in each of the four classical bands. The reason why the spectrum difference ratios were so large for the DZs can be understood when we look at a fifth parameter, the median frequency of the alpha activity, which I call Phi. The MZ twins are again very similar with respect to alpha frequency-their correlation is .81—but the correlation for the DZ twins is only .13 and not significantly different from zero. Since the alpha 'bump' is such a salient feature of the EEG spectrum, DZ twins with different alpha frequencies will show a large rms difference between their

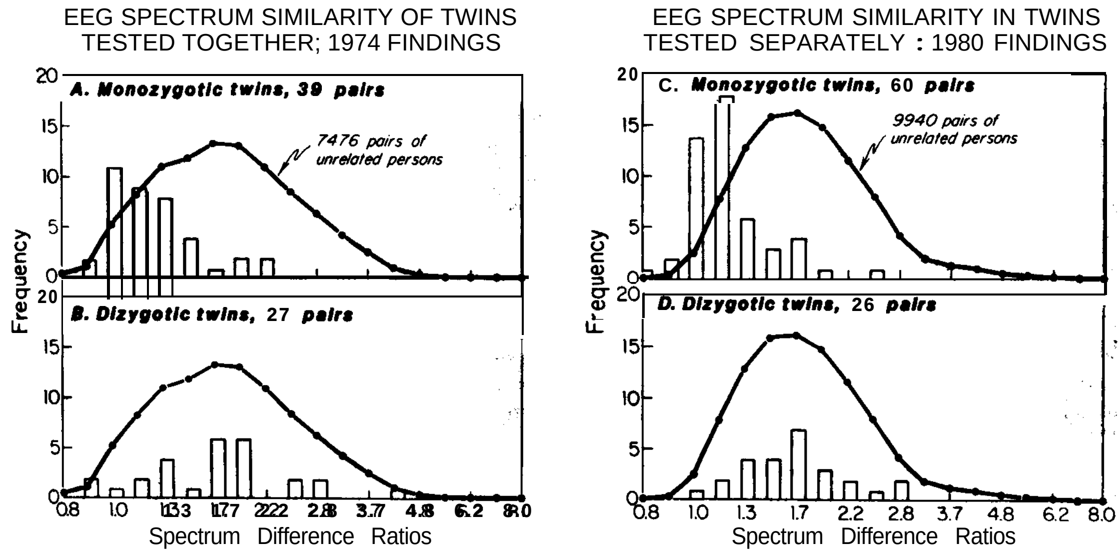

Figure 2. Distributions of the spectrum difference ratio, an index of relative gross EEG spectrum similarity, for samples of MZ and DZ twins compared with a large sample of pairs of unrelated persons. When the SDR equals 1.0 or less, the pairs of spectra are as similar as repeated spectra from the same individuals. In the 1974 study, the spectra of most MZ twin pairs were remarkably alike while those of DZ twins were no more similar than the spectra of unrelated pairs. A new sample studied in 1980, with the EEG recorded from the vertex rather than the occiput and the twins tested days or weeks apart, showed essentially identical results.

spectra even if the,spectra are otherwise reasonably similar.

Thus we see that the center frequency of the alpha rhythm is the spectrum parameter that actually displays the emergenic effect and this is interesting because the frequency of the alpha generator almost certainly involves some sort of resonance phenomenon. One can show that by having a subject look at a light that flashes at a series of frequencies spanning the range from 6 to 14 Hz. Such photic driving will produce a spike in the EEG spectrum at the frequency of the flashes and the height of those spikes will show a sharp maximum at the midpoint of that subject's normal, eyes-closed alpha 'bump.' We do not know for certain what or where the alpha generator is but we do know that resonance is a classic example of an emergent, interactive phenomenon. The resonant frequency of a circuit cannot be predicted as an additive function of the components but only from their configuration. If these components are each strongly heritable, then MZ twins will tend to have similar alpha frequencies. But for DZ twins, even though their components may show intermediate similarity, the alpha frequencies will appear to vary almost randomly because they are a function not of the sum of the components but rather of their product so that modest differences in component values can be amplified into large differences in resonant frequency when they are multiplied together.

"Fluid" Intelligence: An Emergenic Trait?

Let us turn now to a different aspect of brain activity, the domain of intelligence. Bouchard and McGue (1981) recently published a survey of the world's literature on the correlation of IQ in twins and other relatives. As shown in Table 4, in 34 studies of MZ twins reared together, involving more than 4600 twin pairs, the median IQ correlation is .85. In 41 studies of DZT twins, totalling

TABLE 4

Intra-class correlations of several intelligence measures for monozygotic and dizygotic twins raked together (MZT and DZT), for first cousins, and for a small sample of MZ twins raised apart (MZA)

Intelligence Measures	Correlations MZT (N = 4672)	DZT (N = 5546)	cousins (N = 1176)	MZA (N = 29)
IQ[1]	.85	.58	.15	.73
Raven[2]				.58
Mill-Hill[2]				.78
IQ(R + M)[1]				.71

[1]Median scores from a summary of the world literature (Bouchard & McGue, 1981). IQ data for the MZA twins are full-scale WAIS IQs obtained by separate examiners.

[2]These data were corrected for age and sex differences before the correlations were computed. IQ(R + M) is the sum of the Raven and Mill-Hill scores after each had been converted to standard score form.

more than 5500 pairs, the median correlation is about .58. This would suggest a broad heritability for IQ on the order of 54% but this is probably an underestimate. Lykken, Tellegen, and DeRubeis (1978) have shown that DZ twins are only about half as likely as MZ twins are to volunteer as experimental subjects and the DZs who do volunteer are probably more similar within pairs than are DZ twins in general. For this reason, that median DZT correlation may overestimate the true DZ correlation for IQ, leading to an underestimate of heritability.

In our study of twins reared apart, two psychometrists are hired to administer the Wechsler Adult Intelligence Scale (WAIS) simultaneously in separate rooms in order to avoid all possibility of systematic bias or distortion. On the MZA twins we have tested so far, the WAIS IQ correlates .73, which would suggest that, for the British, American and Australian cultures in which these twins were raised, about 70% of the variance in IQ is associated with genetic variation.

Some'radical environmentalists try to account for the similarity in IQ of MZA twins by suggesting that separated twins tend to be placed for adoption in similar homes that are likely to provide comparable intellectual stimulation and enrichment. We are collecting as much information as we can on the adoptive families so that we shall be able to estimate their within-pair correlation for socioeconomic status, parental education, availability of books, magazines, and the like but these analyses have not yet been completed. I do not anticipate, however, that these adoptive families will prove to have been more similar than, say, the families in which biological first-cousins are reared. Bouchard and McGue found four studies, involving more than 1100 pairs of cousins, in which the median correlation was only about .15.

Since the intra-class correlation for DZ twins on a wide variety of IQ tests seems to be reliably greater than half the MZ correlation, IQ as it is usually measured appears to fit the additive polygenic model. Another well-known measure of intellectual ability, however, behaves rather differently. For a number of years, we have been administering the Raven Progressive Matrices and also the Mill-Hill Vocabulary test to adult twins and we use computer administration so that we can measure item response times. The subject sits alone at the computer console and proceeds at his own speed. The MZA twins also take these two tests when they visit my laboratory and the computer administration and scoring ensures that the results are as accurate and unbiased as are their scores on the WAIS. Using norms based on more than 130 pairs of twins tested this way previously, we could convert the Raven and Mill-Hill scores to standard score form and combine them into what I shall call a "British IQ." The MZA twins have an intra-class correlation of .71 on this independent IQ estimate (see Table 5). For 71 pairs of MZ twins reared together, this correlation is .78. But, again, the data from the DZ sample are particularly interesting; for 42 pairs of DZT twins, this British IQ shows a correlation of .14, not significantly greater than zero.

One might suppose that this finding, if it is real, should have been noticed before. It turns out, however, that there has been only one prior twin study using the Raven Matrices (Canter, 1973) and in that one the data were apparently not corrected for either age or sex differences. Since age and sex are identical within each twin pair, then if the variable one is studying varies with age or sex or both, the within-pair correlations are bound to be spurious. We fit parabolas to the regression of test score on age separately for males and females and remove the age and sex effects before doing the within-pair correlations.

In any case, it is unlikely that prior investigators would have noticed this effect. We administer both the Raven and the Mill-Hill as "power" tests, without time limits, and this turns out to be crucial. There is not even the implicit time pressure that is always involved when there is another person in the room waiting for you to finish. This lack of time pressure seems to make an important difference in

TABLE 5

Intra-class correlations of Raven, Mill-Hill, and derived scores for samples of monozygotic and dizygotic twins reared together (MZT and DZT) and MZ twins reared apart (MZA)

	Correlations			
Intelligence Measures	MZA **(N = 29)**	MZT **(N = 71)**	DZT **(N = 42)**	**Ratios DZT/MZT**
Raven	.58	.66	.19	29%
Mill-Hill	.78	.74	.37	50%
IQ(R + M)	.71	.78	.14	18%
Raven/Time	.64	.72	.39	54%
Mill-Hill/Time	.71	.76	.49	64%
IQ(R/T + M/T)	.71	.80	.39	49%

Note.-The composite IQ(R + M) (Raven and Mill-Hill converted toz-scores and added), like the Raven itself, produces DZ correlations that are much less than half the MZ correlations and, thus, appears to be an emergenic trait. When converted to rate-of-processing scores by dividing by the average response time, both the Raven and the composite "IQ" scores produce ratios of DZ:MZ correlations that meet the expectations of the additive polygenic model. (All scores are corrected for age and sex differences before correlating.)

the case of a problem-solving test like the Raven—and perhaps also on other measures of what Horn and Cattell (1966) call "fluid" intelligence. The number of items solved with unlimited time depends not only on how rapidly one can think of alternative possible solutions but also on how long one is willing to think before giving up-on one's persistence-and these two factors probably combine multiplicatively.

Since we have obtained the item response times, which are a measure of persistence, we can test this model by dividing the power score-the number of items correct on each test-by the average time that subject spent thinking about each item, and so get an estimate of rate of processing that is more like what is measured by the score on any speeded test. When we do this separately for the Raven and the Mill-Hill and then again convert to standard scores and combine as before, the MZT correlation is now .80 and the DZ correlation becomes .39. Response time on the unspeeded Raven also turns out to be an emergenic variable; the MZT correlation is .45 while the DZT correlation is −.05. When its effect is removed from the emergenic power score, the resulting estimate of speed of processing-which may be the "g-factor" that runs through typical tests of intelligence-proves to obey the Galtonian additive model. I find this interesting because I suspect that performance on unspeeded problem solving tasks may be a better predictor of achievement in the real world than typical IQ tests have proven to be. If one could unscramble the configuration of motivational and other factors that determine the emergenic variable of persistence, then one might be better able to help people to potentiate or maximize whatever talent they may be endowed with.

The Electrodermal Response

When Bouchard first organized this MZA twin study, my laboratory had been running ordinary twins in an habituation paradigm. Since we were set up this way already, the MZA twins have been run through the same experiment. We present 17 tones (110dB, 0.5 sec) at pseudo-random intervals averaging 60 sec and measure skin conductance in both hands. At the start of the session, the subject is told to expect a loud sound sometime during the next minute; we then present a 110dB blast of white noise which effectively elicits reasonable estimates of his maximum SCR for each hand and these are then used to range-correct (Lykken, Rose, Luther, & Maley, 1966; Lykken, 1972) his responses to the tones. The computer plots the corrected electrodermal response amplitudes against the log of trial number for both members of a twin pair and habituation curves-straight lines on these semi-log plots-are fitted to the data (Figure 3).

Consider now the within-pair similarity for SCR amplitude on the initial trials. Measured in raw micromhos, the mean SCR amplitude over the first 4 trials correlates .55 for MZ twins but −.13 (essentially zero) for DZ twins (see Table 6); SCR amplitude seems to act like an emergenic variable. If we now range-correct these mean responses by dividing each person's raw SCR by his maximum SCR, the MZ correlation becomes .65 and the DZ correlation is .37-the range-corrected amplitudes fit a polygenic additive model.

Why should this be? The skin conductance response generated by a given sudomotor impulse will vary from person to person depending on the physiological characteristics of the palmar skin and especially upon the density and reactivity of the

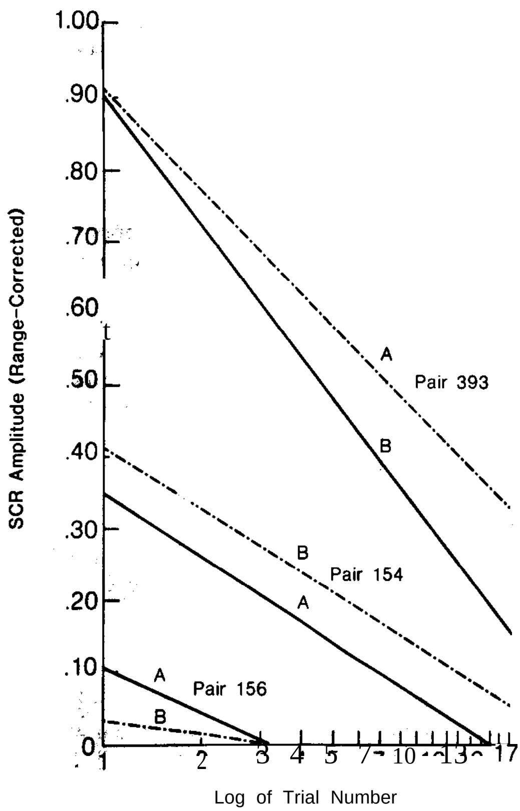

Figure 3. Habituation of the skin conductance response (SCR) to a 110dB tone stimulus (0.5 sec, 20–90 sec ISI) in 3 pairs of adult MZ twins separated as infants and reared apart. The SCRs have been range-corrected by dividing by that subject's maximum SCR. Of the 27 pairs of MZA hvins tested so far, the electrodermal habituation curves of 4 pairs are clearly discordant. For 63 pairs of MZ twins (including 36 pairs reared together), the intra-class correlation of the slopes of these habituation curves is about 0.80.

TABLE 6

Intra-class correlations of skin conductance response (SCR) amplitude (mean of first 4 trials of habituation series) with and without range correction, maximum SCR, and maximum and minimum skin conductance levels (SCLs) for MZ and DZ twins

	Correlations			
Skin Conductance Variables	MZ **(N = 64)**	**DZ (N = 18)**	**Ratios** DZ/MZ	Correlations With **Age**[a]
Initial SCR (raw)	.55	−.13	0%	−.20
SCR (range-corrected)	.65	.37	57%	.04
Maximum SCR	.45	−.12	0%	−.42
Minimum SCL	.62	.02	3%	−.36
Maximum SCL	.61	−.14	0%	−.51

Note.—**Raw** SCR is infected with measurement error (which reduces the MZ correlation), behaves like an emergenic variable (the **DZ correlation** less than half the MZ), and is negatively correlated with age. Range correction eliminates these problems. Note that maximum and minimum skin conductance levels **(SCLs)** and the maximum SCR itself are emergenic variables also and substantially correlated with age.

[a]N = 176, number of individuals on which the **product-moment** correlations with age are based.

palmar sweat glands. Conductance change is determined both by the strength of the efferent nerve impulse and the reactivity of the **effector** organ and this function is almost certainly multiplicative. MZ twins will show similar CNS responses to the stimuli and their skin will tend to be reactive to a similar degree; they will therefore show similar SCR amplitudes. But **effector** reactivity, as estimated by maximum SCR in Table 6, is a configural or **emergenic** characteristic. Therefore, DZ twins show little similarity in raw SCR amplitude. Range-correction serves to divide the raw SCR by a rough estimate of individual differences in **effector** reactivity, leaving behind a purified measure of the CNS response which, it appears, obeys the Galtonian model.

Some Personality Variables

Over the past 12 years, Auke Tellegen has developed what I think is the best available inventory for assessing normal personality traits (Tellegen, Note 2), the Differential Personality Questionnaire. I have administered the DPQ to a large number of ordinary twins and it is also one of the 8 personality inventories that our MZA twins are required to complete. One of the 11 scales of the DPQ is a measure of Conservatism, an affinity for traditional values including strong allegiance to established authority. Another scale is called Social Potency and measures one of the dimensions usually **conflated** in measures of extraversion. The data indicate that one of these traits obeys the additive model while the other seems to be an **emergenic** trait; the reader might want to try to predict which is which. One trait behaves as if its component parts are additive or supplementary; the other behaves more like a product of its components so that, for example, if either component is very small then the trait score cannot be very high.

One might be inclined to doubt that Conservatism-the tendency to endorse conservative traditional values-has any genetic basis at all. The fact that this trait correlates .74 in our sample of MZA twins, however, suggests that the genetic influence actually is considerable; perhaps William Buckley Jr. and I. F. Stone, Jr. owe their positions on the political spectrum as much to their genomes as to the example set by their parents. If someone has a high (or a low) score on Conservatism, we can predict not only his political views, but also his attitudes toward established religion, toward racial differences, capital punishment, abortion, "unleashing" the police, toward the Communist Party (a conservative's attitude toward the Communist Party will be "anti" if the person is American, "pro" if he's Russian); we can predict his views on gun control, welfare, the MX missile, and so on and on. Conversely these correlated attitudes, all influenced perhaps by some genetic inclination to march to the music of the same big drum, add up to yield the score on Tellegen's Conservatism scale. The age- and sex-corrected correlation for 247 pairs of MZT twins is .58 and the correlation for 122 pairs of DZ twins is .44.

Social Potency, on the other hand, measures the self-perceived ability to influence, lead, or dominate others and the amount of social impact one has-the amount of leading or influencing one does-probably depends on some configuration of attractiveness, self-confidence, assertiveness, dominance-whatever the ingredients are of 'charisma.' Our MZA twins correlate .67 on Social Potency and the 247 pairs of MZT twins are correlated .65. The 122 sets of DZ twins, however, correlate .07, nearly zero; Social Potency is the emergenic trait.

Two second-order factors in the DPQ are called Positive and Negative Affect. People with high scores on Positive Affect have a capacity to experience joy, enthusiasm, feelings of trust and gratification, and to behave in ways conducive toward such experiences. High scores on Negative Affect reflect a tendency to feel fearful, worried, suspicious and dissatisfied and to act in ways that tend to perpetuate such misery; Eysenck's Neuroticism (1953) and Block's factor of Ego **Resiliancy** (1965) represent essentially the same dimension. Interestingly, Positive and Negative Affect are nearly orthogonal so that it is not difficult to find people who have high (or low) scores on both of them. As can be seen in Table 7, Negative Affect shows moderately high correlations in both types of twin and also in twins reared apart. Positive Affect, in contrast, while the correlations among both MZA and MZT twins indicate a significant genetic influence, shows no within-pair similarity at all among DZT twins. The capacity for happiness, while certainly dependent upon genetic endowment, is apparently more a function of the interaction of one's traits (e.g. of temperament) than of some simple algebraic sum; Positive Affect appears to be an emergenic trait.

Recreational Interests

Some time ago I devised a rating-scale inventory of recreational interests that turns out to have 8 factors concerned with interests in things like sports, gambling, cultural activities, intellectual pursuits, and so on. The Blood Sports factor, which involves hunting, shooting, trapping, and the like, is positively correlated with interest in football and baseball-the Sports factor-and with watching TV, partying, and snowmobiling-the Entertainment factor. But Blood Sports is negatively correlated with Cultural and Intellectual interests and also with what I call the Sierra Club factor, which involves interests in camping, visiting the wilderness, animals, and physical fitness. Another dimension I call Husbandry and it involves making and fixing things, gardening, craft work, and the like.

Let me focus your speculation on the Blood Sports, Intellectual, Husbandry, and Sierra Club factors. One of these seems to have moderate genetic loading and the DZ twins are about half as similar as the MZs. Two factors have considerable genetic loading but also a strong environmental influence; the MZA twins are strongly correlated but so are the DZT twins. Finally, the fourth factor appears to be emergenic.

The findings are shown in Table 8. The MZA twins correlate .80 on Blood Sports but the DZT twins also have a high correlation; we have an instinct to kill things that varies from genome to genome but it is readily modified by mutual influence in twins reared together. Intellectual interests display a similar pattern. The idea that hunters are especially interested in wildlife and wilderness is not supported by these data, but that sort of interest does form a separate dimension, the Sierra Club factor, which is moderately influenced by the genome and obeys the polygenic additive model. It is the important dimension of Husbandry, an interest in building, fixing, decorating, and growing things, that turns out to be emergenic. Husbandry is correlated .65 in MZA twins, .55 in MZT twins, but essentially zero (- .07) in DZT twins.

Conclusions

Our study of twins reared apart is a long way from completion and my colleagues are maintaining a proper attitude of scientific caution and reserve about what it all means. Although I am more inclined than they are to jump to conclusions, even I recognize that there is still much to be done and that no one can be very sure about the implications, especially until they are tested by other investigators using other methods. Nevertheless, I have

TABLE 7

Intra-class correlations for two scales and two second-order factors from Tellegen's Differential Personality Inventory

Tellegen Inventory Variables	Correlations MZA (N=28)	MZT (N=247)	DZT (N= 122)	Ratios DZT/MZT
Social Potency	.67	.65	.07	11%
Conservatism	.74	.58	.44	76%
Positive Affect	.57	.63	.02	3%
Negative Affect	.65	.67	.43	64%

Note.—Results for MZ twins reared apart (MZA) suggest that all four variables display genetic variation. High correlations among DZ twins reared together (DZT) suggest that Conservatism and the Negative Affect factor are strongly influenced by learning in a shared environment. In contrast, Social Potency and the Positive Affect factor appear to be emergenic traits.

TABLE 8

Intra-class correlations for four recreational interest factors

Recreational Interest Factors	Correlations MZA (N=28)	MZT (N= 140)	DZT (N=70)	Ratios DZT/MZT
Blood Sports	.80	.54	.68	126%
Sierra Club	.49	.57	.28	49%
Intellectual	.69	.46	.42	91%
Husbandry	.65	.55	−.07	0%

Note.—MZ twins reared apart tend to be more similar than twins reared together but this may be a sampling artifact. MZA and DZT correlations both are relatively high for interests in Blood Sports and Intellectual pursuits, suggesting that these traits possess considerable genetic loading but also that they are rather easily modified by mutual influence. Interest in wilderness, camping, animals, and physical fitness (the Sierra Club factor) behaves like a polygenic additive trait. Husbandry, an interest in building, fixing, decorating, and growing things, appears to be an emergenic trait.

come to some personal conclusions which I shall state now in the form of hypotheses or speculations that I think subsequent research, our own and I hope research by others, will verify and illuminate. Here they are.

(1) I think, first, that much more of the variance in human behavior is genetically based than we have previously supposed. Some environmentalists find such a view distasteful, implying some kind of predestination, blind biological determination, a view of the human animal as a mere puppet, dancing on strings manipulated by the genome. I think such people must never have worked with real, live twins and discovered how complex and individual they are, for all their similarity. Remember that the hands that twins are dealt in the great genetic card game, while identical, are very large hands, rich in potentialities only some of which, in the usual life, are ever realized. Most MZ twins tend to be very much alike because the circumstances of life in our affluent society permit most of us to play out our hands in the obvious way. When the challenges and opportunities that confront them are very different, even monozygotic twins may exploit different aspects of their common inheritance and thus become different in significant ways. If our next 50 pairs of MZA twins also show a high correlation on Conservatism, this will not mean that, e.g., Republicans are incorrigible. If Hubert Humphrey's and Barry Goldwater's sons had been mixed up in the hospital nursery, who could doubt that their political sentiments would have followed those of their adoptive parents? It will mean, rather, that the political education and shaping that we provide our children is, on the average, unsystematic and weak. Heritability estimates tell us more about human culture than about human nature.

None of the twins we have seen have felt diminished or de-individualized as a result of meeting another person constructed on the same blueprint. Their reunion does not make them start to feel like robots. Instead they feel enriched, with greater self-esteem and wider horizons than they ever felt as singletons.

(2) I believe that many of the ways in which the genome influences behavior involve the mechanism I have called emergenesis; the phenotypic characteristic is produced by an interaction of independent genes or by a configuration of component traits that are themselves genetically determined. Since emergenic traits do not tend to run in families, they have been neglected by behavior geneticists. When we see these idiographic similarities in ordinary twins, we immediately attribute them to shared learning experiences, mutual modeling, and the like. It is only when we see these similarities in twins reared apart that we are forced to reconsider their significance.

(3) There seems to me to be little doubt that emergenesis is a real phenomenon, at least at the molar level and probably also at the level of the genome. The question still to be answered is how important it is, how much of the significant behavior of the average individual is emergenic in origin. This is important in part because emergenic traits often tend to be unique, idiographic rather than nomothetic in character. If emergenesis plays an important role, then Gordon Allport's vision of the future of psychology may prove to be closer to reality than Hans Eysenck's vision.

(4) In any case, we can recognize that emergenesis is just one more of Nature's many methods of ensuring variability within species. Galton's additive model implied that all the good traits would eventually become sequestered among the few families of a privileged aristocracy, a view that no doubt seemed to fit the realities of Victorian England. Because of emergenesis, however, genius can and does spring up in unexpected places. As far as our emergenic traits are concerned, while we remain creatures of our genes, at least we are not hostage to our ancestors. Emergenesis, I believe, is an engine of convection that provides circulation both up and down the strata of a healthy society. It is the reason why the Cabots and the Lodges of the 21st Century may turn out to have familiar names like Jukes and Kallikak.

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