

**Reports from the Research Laboratories  
of the  
Department of Psychiatry  
University of Minnesota**

**Psychometric Applications of the EEG**

**by**

**DAVID T. LYKKEN**

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P95  
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## Psychometric Applications of the EEG<sup>1</sup>

David T. Lykken

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More than 40 years ago, Berger first reported that faint electrical activity, apparently originating in the brain, could be recorded from the human scalp. Since that time, although the inevitable iconoclasts have tried to attribute this activity to non-cerebral sources, a mass of evidence has accumulated in support of Berger's original conclusion --- the electroencephalographer can indeed eavesdrop on at least some of the spontaneous activity of the body's most complex and mysterious organ. Such a 'window on the brain' is a source of fascination not only for the neurophysiologist but for the psychologist as well since the brain is the great mediator of virtually all behavior of any psychological interest. Spinal reflexes excluded, if a stimulus is to affect behavior it must first affect the brain and some aspect of that effect may be visible through the window of the EEG, as in the cortical evoked response for example. Individual differences in behavior dispositions, including important constitutional differences

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in aptitude, temperament, and psychiatric diathesis, must have their origin in differences in brain function which again might be seen through the window if one only knew where and how and when to look.

To cite a specific example, Berger's first discovery --- the so-called 'alpha rhythms' of the EEG --- have received considerable recent attention. These are defined as roughly sinusoidal waves of from 8 to 13 Hz which appear in the waking EEG, especially when the subject is relaxed and has his eyes closed. These alpha waves have such high amplitude, on the order of 100 microvolts, that Berger was able to record them clearly on his primitive equipment. Biofeedback experiments have lately shown that it is possible to train subjects to increase their spontaneous alpha activity and that they find the feeling state associated with this increased alpha to be relaxing and enjoyable. It is even possible to train some subjects to increase alpha selectively on one side of the brain.

One of the most interesting speculations about the alpha rhythm is the notion that it represents the ticking of one of the biological clocks, that alpha is associated with a kind of scanning or gating process involved in stimulus input regulation and in cognitive processing. Lansing showed in 1957 that reaction times were quickest to visual signals which reach the visual cortex at a critical portion of the alpha cycle (the negative zero-crossing) and Surwillo (1963, 1964) has reported correlations of more than .7 between alpha period and reaction times

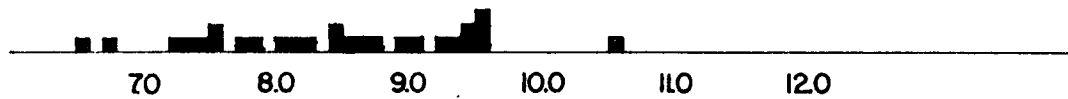
(although Boddy (1971) has since called Surwillo's findings into question).

Beginning with Craik in 1948, data have accumulated in support of the notion that the brain operates in a discontinuous or temporally segmented fashion, at least in respect to cognitive processing. Two related hypotheses, concerned with excitability cycles and the idea of cortical scanning, have been ably reviewed in a paper by Harter in 1967. An interesting example of this approach is the theory of central intermittancy proposed by Kristofferson (1967) in which alpha figures as the central clock which determines the "moments" --- from about 8 to 12 per second --- during which attention can be switched from one input channel to another or when one stage of central processing can transmit its product to the succeeding stage.

These few illustrations may be enough to suggest that alpha abundance and alpha frequency may be variables of considerable psychological and even clinical interest. But this, in turn, requires that we look at these and other EEG variables with the scrutineering eye of the psychometrist, just as we would some alleged personality or aptitude measure. For example, Figure 1 shows some unpublished data from a study done with Peter Venables and John Gruzelier at a psychiatric hospital in London in which 1-minute resting, eyes-closed EEG samples were obtained from 27 chronic schizophrenic patients. The figure indicates that the mean alpha frequency was about 1.5 Hz lower for the schizophrenics than for a control group of non-patients.

### DIFFERENCES IN EEG ALPHA FREQUENCIES

A, CHRONIC SCHIZOPHRENIA, MALE (N=27)



CONTROLS, MALE (N=35)



MEAN ALPHA FREQUENCY IN HZ (Sc mean=8.4 HZ; Control mean=9.9 HZ,  $t=6.37$ )  
DATA OBTAINED FROM MAGNITUDE SPECTRA BASED ON  
1 MINUTE SAMPLES OF RESTING EEG, EYES CLOSED, VERTICAL LEAD.

Figure 1

This difference is highly significant and one might be tempted to relate it at once to the slowing of cognitive processing of schizophrenia and, with a little ingenuity, even to schizophrenic disorders of attention. But a first question to ask is whether this result is replicable; too often in psychology great effort has been spent on explaining findings which turn out later to be unrepeatable. This in turn raises questions like the following: Asked to find the alpha frequencies of a group of patients, would any two competent investigators

produce essentially equivalent EEG samples? And would their independent analyses of the same EEG samples yield nearly identical estimates of alpha frequency? And would repeated testing of the same group of subjects produce similar results each time? More generally, by what logic do we set the limits of alpha activity at 8 and 13 Hz in the first instance? By usual psychometric standards, this would imply that EEG activity at, say, 8.1 Hz has more in common with activity at 12.9 than at 7.9 Hz; what evidence supports that improbable contention? The truth seems to be that adequate techniques for studying these problems have only recently become available and that most of the necessary work has yet to be done. Meanwhile, there has accumulated a great wealth of clinical lore and data based on inadequate or at least idiosyncratic techniques; no doubt much of this body of doctrine is true but surely some of it is false and the problem is to tell the difference.

#### Spectral Analysis of EEG

One convenient way of studying the frequency characteristics of an EEG sample is by means of spectral analysis. The EEG signal, either on-line or by means of tape recording, is fed into a computer which produces histograms of the types shown in Figure 2. These four magnitude spectra represent analyses of 3-minute eyes-closed EEG samples from both members of two fraternal twin pairs. The X-axes here are calibrated in cycles-per-second (Hertz) and the ordinates can be interpreted in terms of microvolts input at the given frequency.

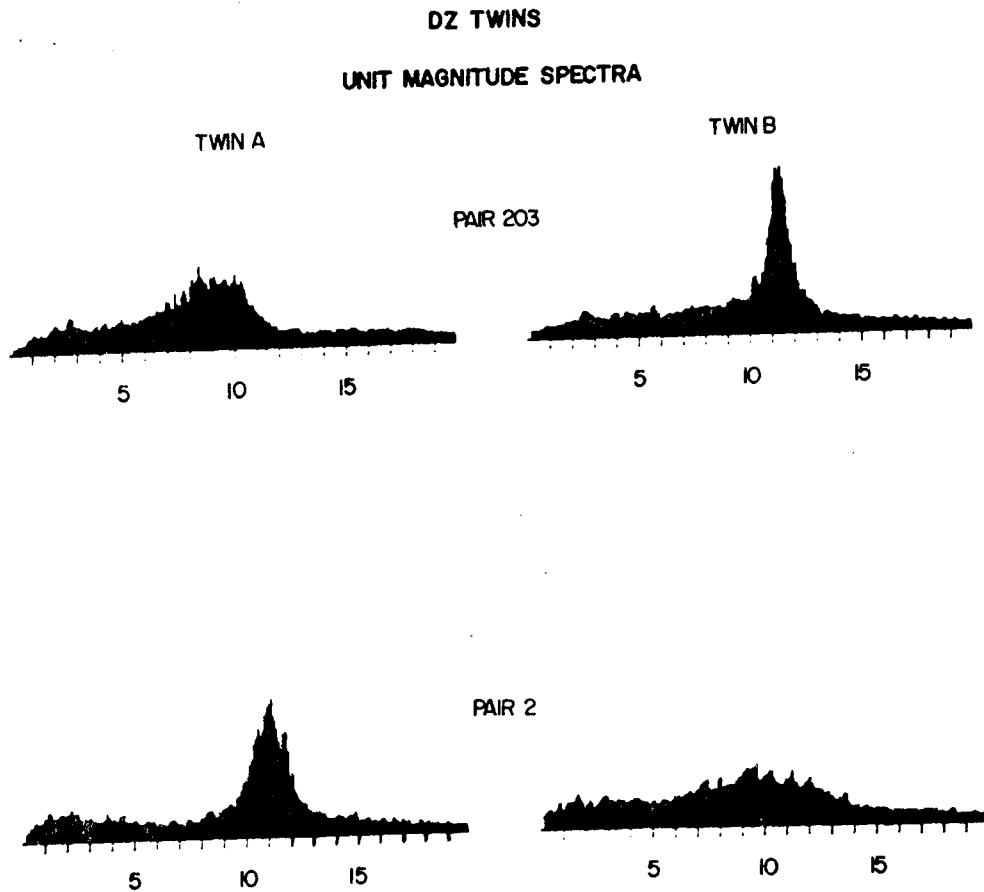


Figure 2

A rough idea of how one can interpret such spectra can be deduced from the statement that Twin A of Pair 2 had more alpha activity in his sample than did his later born co-twin and that the alpha for both of these twins varied more in frequency during the 3 minutes than did that of Twin B in Pair 203.

We can get a clearer understanding by having a look at what spectral analysis does with input that is simpler than the EEG. The whole method is based on Fourier's Theorem which, (mathematicians please forbear) I shall now state in clear and simple language which the human



mind can comprehend. Fourier tells us that just about any squiggly line, like those we record on a polygraph chart, can be synthesized by adding together a number of pure sinewaves, of different frequencies, amplitudes and phase relationships. For example, to make the curve shown at the top in Figure 3, I set three sinewave generators going at 4, 5, and 8 Hz, respectively, and at about equal amplitudes, and then merely added their outputs together and fed them to the polygraph. The second curve is the sum of pure sinewaves of 10, 12, and 14 Hz, and the bottom curve was formed by adding the first two and, hence, is the sum of six sinewaves.

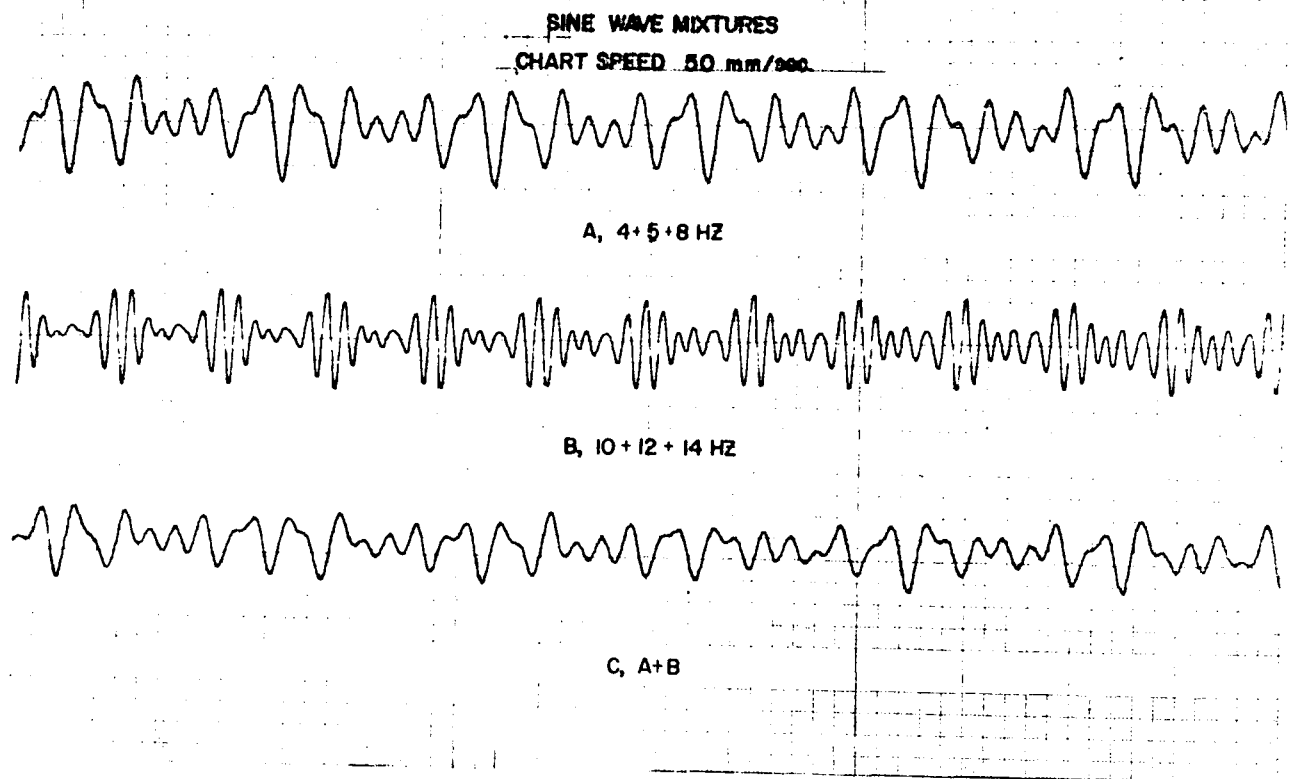


Figure 3

When we feed these three synthesized signals into the computer for spectral analysis, we get the result shown in Figure 4. Spectrum A shows spikes of about equal height at frequencies 4, 5, and 8 Hz; that is, the computer is telling us that our signal could have been composed of equal parts of these three pure sinewaves. Now, of course, our signal need not have been actually synthesized from sinewaves but might have been produced naturally by some device or even by the brain; the spectrum tells us only that an identical signal could have been so synthesized and that this recipe, equal parts of these three sinewaves, is an adequate characterization of that signal. The second spectrum shows spikes at 10, 12, and 14 Hz, as it should, and also reveals that my 12 Hz generator was accidentally set to a slightly higher amplitude than the other two. Happily the third spectrum shows six spikes, all in their proper positions.

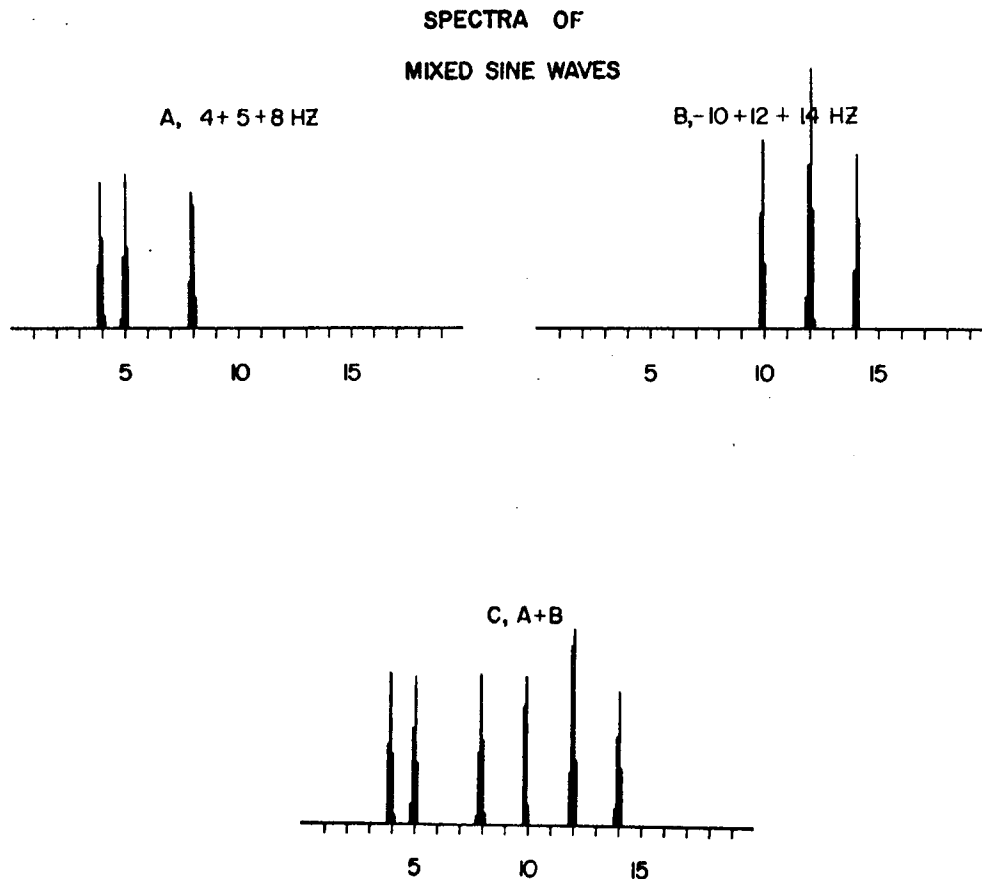


Figure 4

It is worth mentioning that we could have produced, say, the first spectrum with a single sinewave generator by setting it at 4 Hz for one-third of the sample time, quickly switching it to 5 Hz for the next third and then to 8 Hz for the last. That is, the height of each spectrum ordinate is proportional to the product of the amplitude of the given frequency component times the time during which that frequency component is present in the input sample. Thus, a given 'alpha bump' on an EEG spectrum could be produced either by intermittent alpha activity at high amplitude or by more continuous activity at lower amplitude. The computer actually produces two other histograms, called the sine and cosine spectra, from which it is possible to uniquely characterize the input sample and, hence, to distinguish between intermittent high alpha and continuous low alpha, for example.

Figure 5 shows a polygraph write-out of four different wave-forms, all at a fundamental frequency of 5 Hz. From top to bottom, these are known as sinewaves, triangular waves, square waves and ramps. Spectral analyses of these four waveforms are shown in Figure 6. The sinewave shows just the single spike at 5 Hz. The triangular wave, very much like a sinewave except less curved and more pointed, turns out to be analyzable into a large sinewave at the fundamental frequency and a very small sinewave at 15 Hz, the third harmonic. The square wave appears to be a blend of all the odd harmonics, 1st, 3rd, 5th, and so on, in decreasing amplitudes. The recipe for a ramp is to mix all

FOUR 5 HZ WAVE FORMS  
CHART SPEED 50 mm/sec

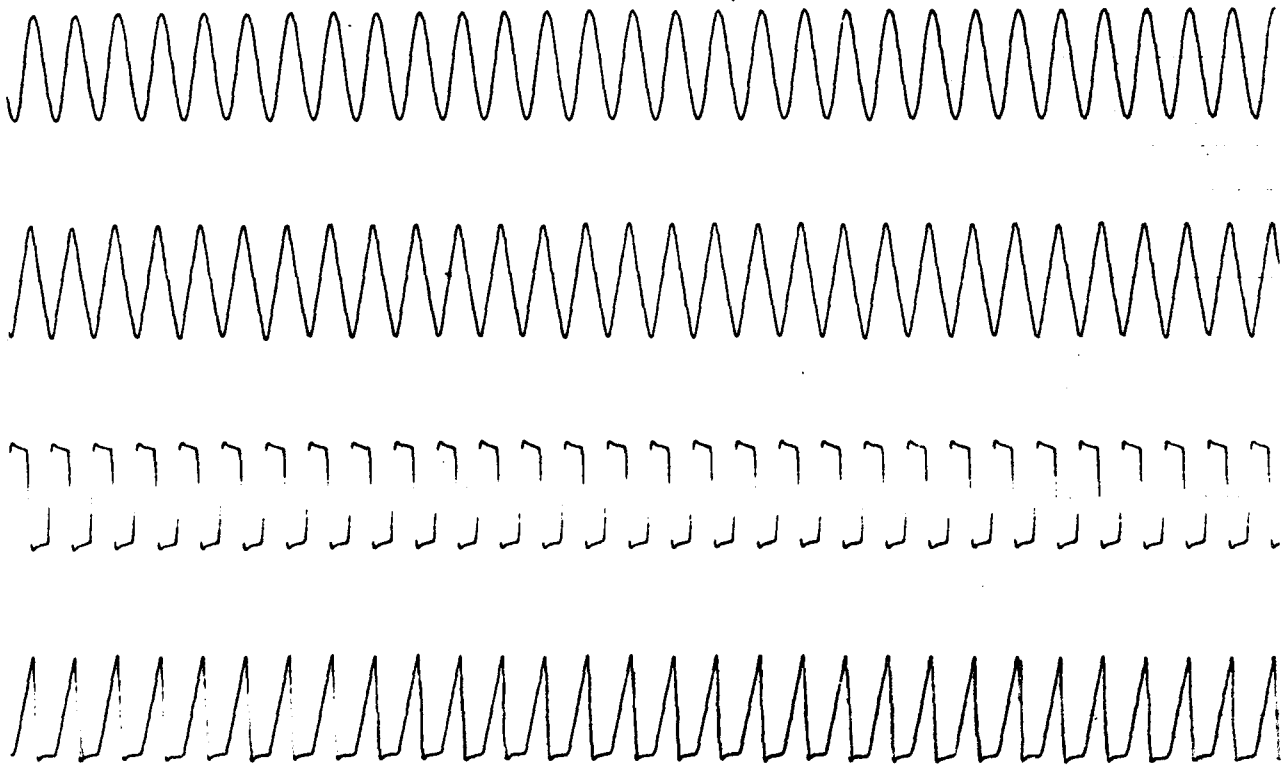


Figure 5

FOUR WAVE FORMS  
MAGNITUDE SPECTRA  
0-40 HZ

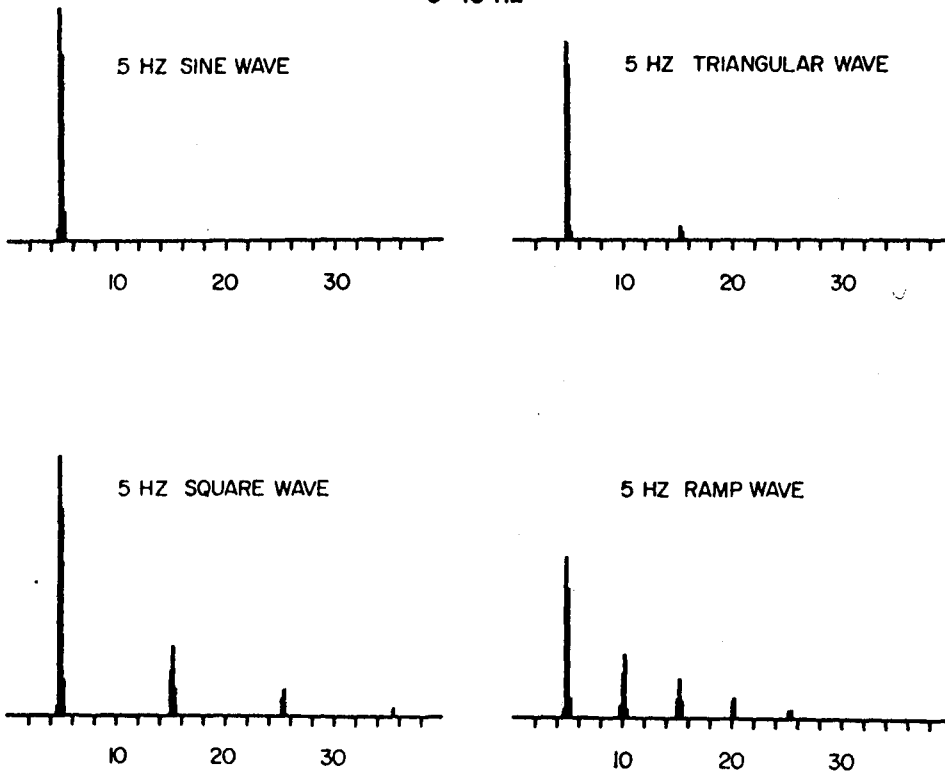


Figure 6

the harmonics in the proportions shown. Finally, Figure 7 illustrates a test of one of these spectrum recipes. I set my three generators to frequencies corresponding to the first three odd harmonics of 5 Hz, and with amplitudes as shown and then added them to produce the curve at the bottom. The result is as close to a square-wave as one could reasonably expect when only the three main ingredients of the recipe are used.

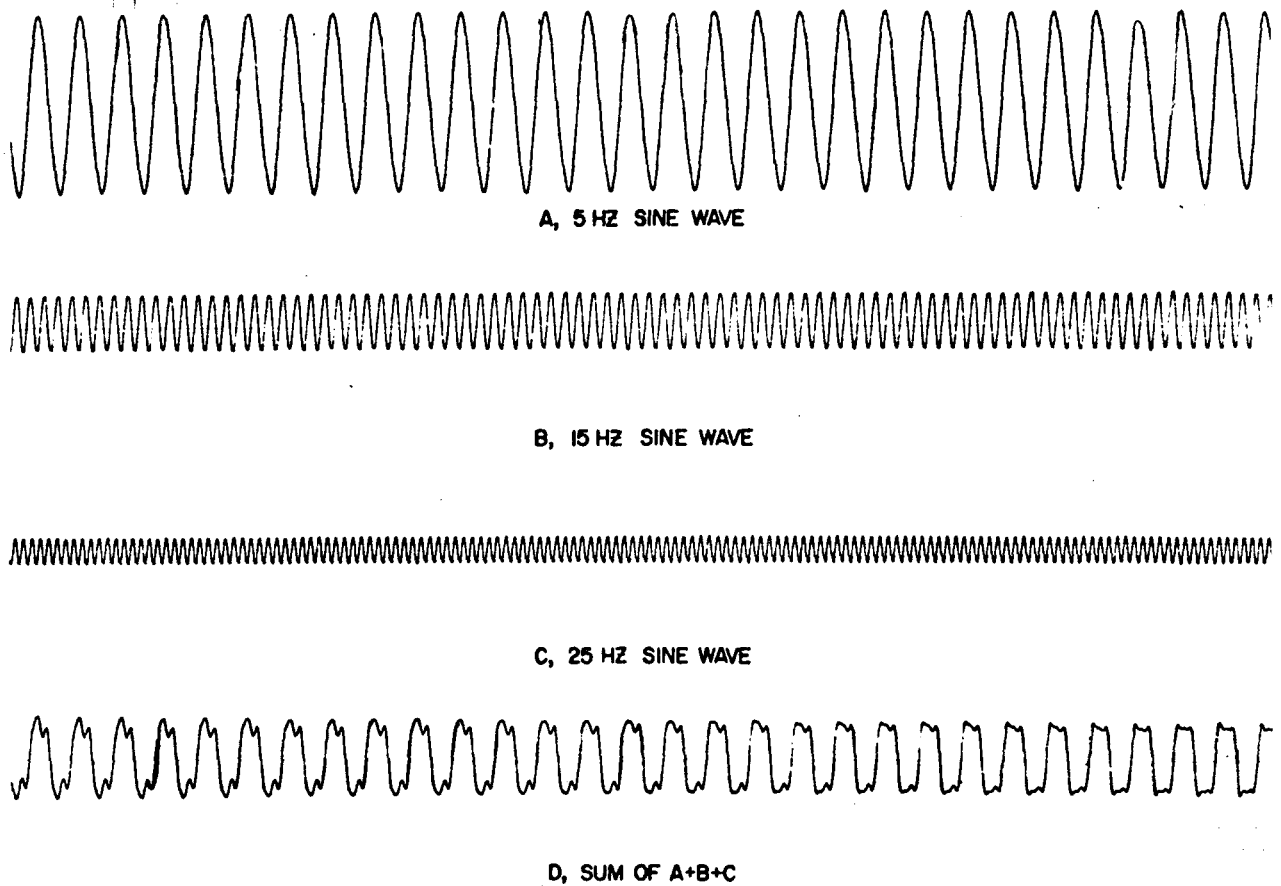


Figure 7

### EEGs of MZ and DZ Twins

Having satisfied ourselves that the magnitude spectrum provides a convenient, quantitative and reasonably fine-grained analysis of the frequency characteristics of an EEG sample, we can turn now to a comparison of EEGs obtained from monozygotic and dizygotic twins. When electroencephalography was still in its infancy, it had already been noticed that polygraphic records of EEGs produced by identical twins are often very similar and the literature abounds with references to that effect. The most recent and best quantified study is that of Young, Lader & Fenton (1972) who recorded eyes-closed EEG from a sample of 32 adult male twins. The abundance and the mean amplitude of alpha activity were measured from the EEG tracings and gave intra-class correlations from the 17 MZ pairs of .51 and .42, respectively, as compared with .16 and .31 for the 15 DZ pairs. The amount of activity in four frequency bands was also quantified by passing the tape-recorded EEG through band-pass filters; the mean correlations for these four variables were .61 and .39 for the MZ and DZ pairs, respectively. The data I am about to show you suggest that the heritability of EEG frequency characteristics may be even greater than would be indicated by this British study, provided that one starts with the standardized spectrum as the basic datum.

Subjects in this experiment were 66 pairs of same-sex twins; all students at the University of Minnesota, who had been carefully diagnosed for zygosity by blood typing (14 systems) and by analysis of fingerprint

ridge counts after the method of Slater (19 ). In combination, these data allow us a confidence of at least .99 that the 39 MZ and 27 DZ pairs were each correctly classified. The twins sat side by side in the dimly lighted experimental chamber with a screen between them and an observer behind them. One channel of EEG was recorded from each twin, between electrodes on the vertex and the right ear lobe, with the left ear lobe serving as ground. The EEG together with the electrocardiogram was recorded via a Beckman Dynograph onto FM tape continuously for the one-hour experimental session. During this hour, the subjects listened through earphones to a pre-recorded standard hypnotic induction procedure, featuring the voice of my colleague, Auke Tellegen, whose Dutch accent and gentle, psychotherapist's manner combine to make him an effective Svengalli. At the start of the session, the subjects are asked to sit quietly with eyes closed for 3 minutes of physiological recording and this three minute sampling was repeated again at the end of the hour, at which time the susceptible subjects were in fact in the hypnotic state. These two 3-minute EEG samples were subsequently analyzed from the tape by a PDP-12 computer which yielded the spectra that I am about to show you.

Figure 8 shows a segment of raw EEG from two pairs of DZ twins. It is apparent that the tracings from the bottom pair are more similar than for the pair on the top, that Twin B of Pair 3 on top produced

TWO DZ PAIR 6 SECOND OF EEG @ 50mm/sec

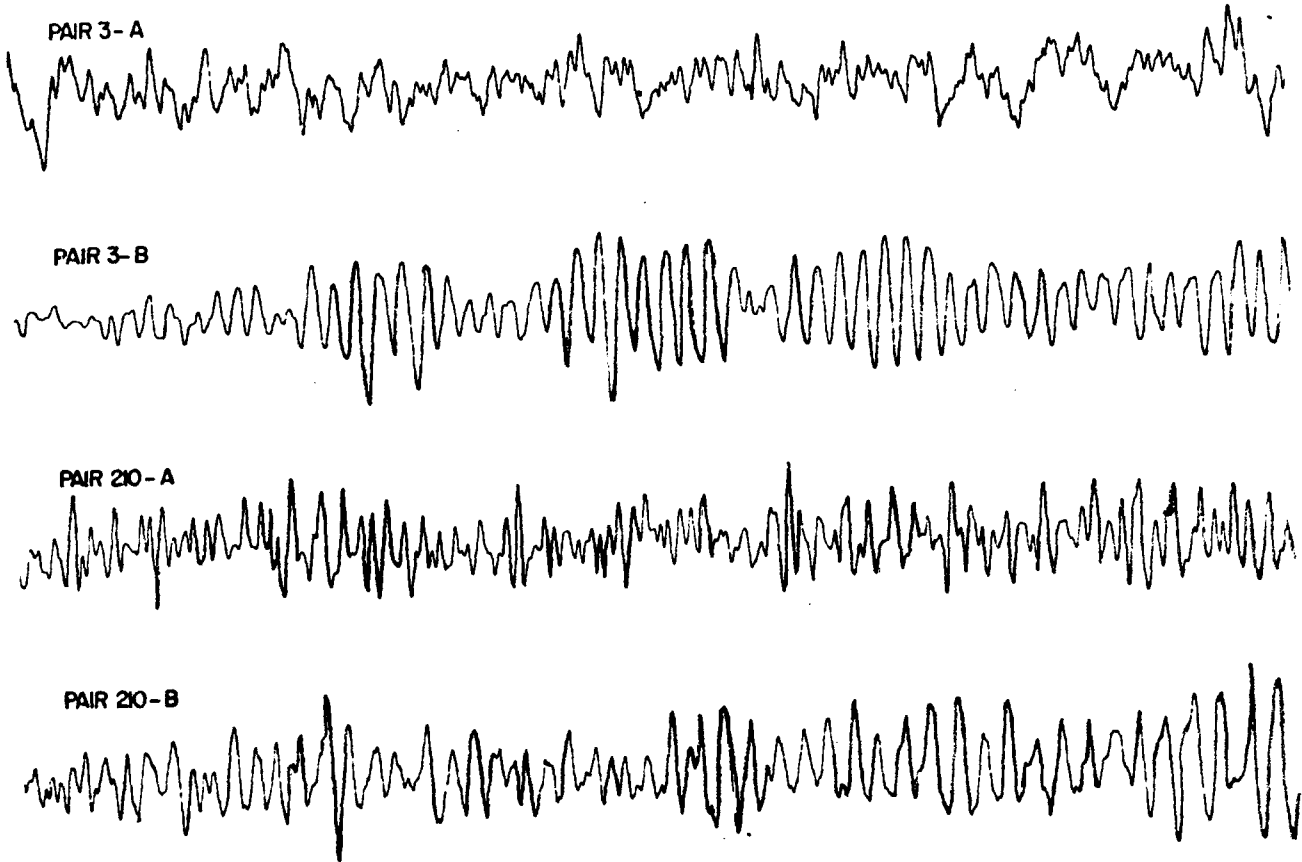


Figure 8

a lot of alpha activity while his earlier-born co-twin produced very little, and one can also see, though less dramatically, that Twin B of the lower pair also was a somewhat better alpha generator than his co-twin. These frequency relationships are considerably clearer when we look at the magnitude spectra for these same twins in Figure 9. By way of contrast, Figure 10 shows four spectra from an MZ pair; samples 1 and 2 were the 3-minute rest periods at the start and end of the session.



Figure 9  
DZ TWINS

UNIT MAGNITUDE SPECTRA

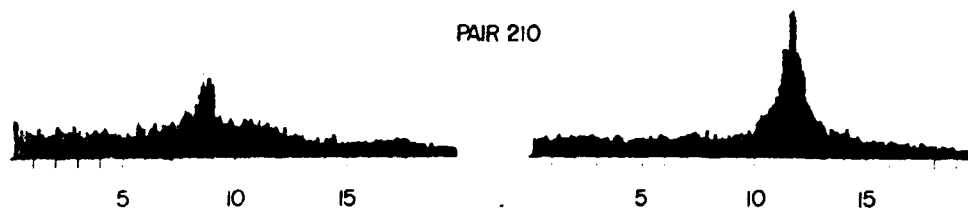
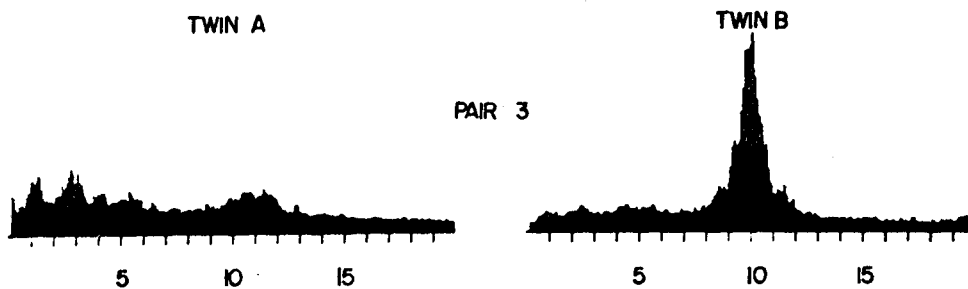
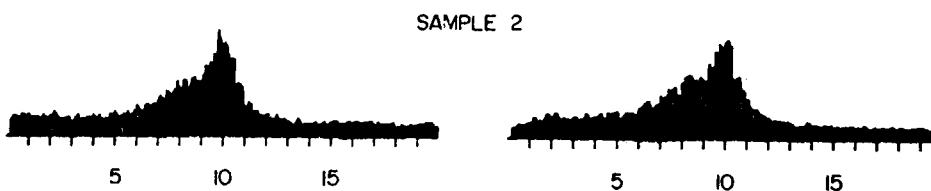
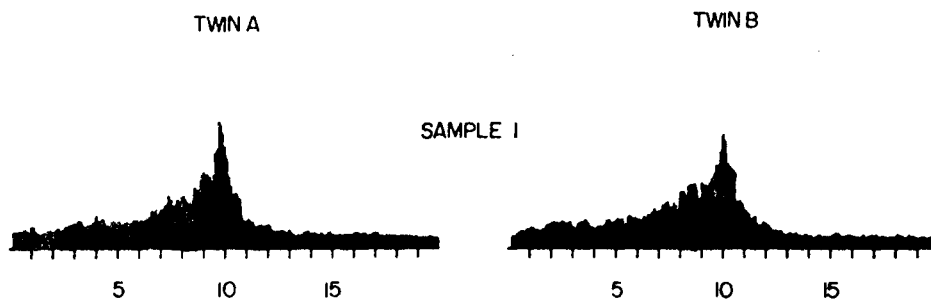


Figure 10  
MZ TWINS, PAIR 319

UNIT MAGNITUDE SPECTRA



One might agree that these could be four samples from the same head.

All the spectra have been modified by the computer so that the total spectrum area --- the dark area in the figures --- is set equal to a constant; this is the process we call "standardization." The same four spectra we have just seen to be so similar are shown unstandardized in Figure 11.

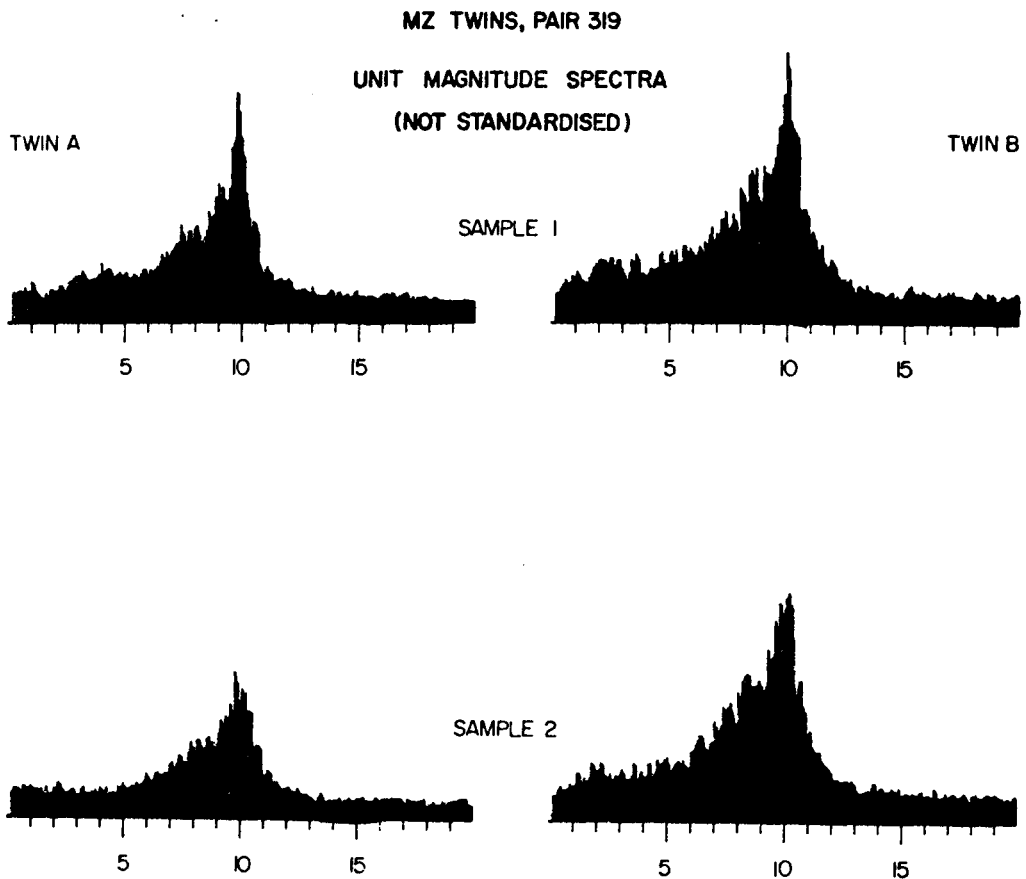


Figure 11

As this illustrates, standardization enhances the similarity of spectra obtained at different times from the same subject or of spectra from genetically identical subjects. What standardization does, in fact, is to partial-out differences in average apparent EEG amplitude, the amplified and recorded signal being played back into the computer. There are, of course, real and presumably meaningful differences in the mean size of the tiny voltages produced by the brain and these differences are lost in standardization. But recorded amplitudes are more strongly affected by factors which represent essentially errors of measurement. Small differences in the gain of any of the several stages of amplification which augment the original signal 10,000 times, differences in electrode resistance, in the location of the electrode on the scalp, in the thickness of the skull, and so on, all constitute a kind of noise which standardization removes.

This small example illustrates a useful general principle of psychological measurement: viz., where alternative methods are available, that one is to be preferred which yields the more orderly data. Usually, stability is an aspect of orderliness, and for this reason we prefer methods which give higher re-test reliability. In this case, spectra obtained from the same place on the same head under similar conditions but at different times are more similar or constant after standardization. The example also illustrates one of the advantages of using twins as subjects in psychological research. For many purposes, MZ twins can be thought of as "parallel forms" of the same subject; it is frequently reasonable to assume that a method

which increases within-pair similarity probably does so by reducing errors of measurement. We have prior reason for assuming that MZ twins should have similar spectra and therefore since standardization of the spectra reduces the ratio of within- to between-pair variance, we can conclude that there is more bathwater than baby in what is being thrown away in standardization and that the method is a useful one.

Figure 12 shows spectra from two more MZ pairs, also very similar. The computer has calculated alpha frequency for us by locating the peak of the 'alpha bump' and then computing the mean frequency within a 3 Hz band centered on that peak. "Alpha percent" is the proportion of the total spectrum within a 3 Hz band centered on that calculated mean frequency. Both members of Pair 323 have an identical high alpha frequency of 11.6 Hz and an alpha abundance of 33%. Pair 104 have a low alpha frequency, 8.7 Hz, and a somewhat greater abundance. It should be noted that alpha abundance, defined from the spectrum, is the product of what other authors have called "alpha index" and "alpha amplitude." Figure 13 shows two more MZ pairs, very similar as usual, with the pair at the bottom being typical of that 6 or 7 percent of subjects who are said to show no alpha activity, a trait which Vogel (1970) has shown to behave like a simple autosomal dominant. The spectrum reveals that, while there is virtually no 'alpha bump,' there is in fact activity from zero to 20 Hz and about 20 percent of the total activity is in the alpha range. But the spectrum is essentially flat and the raw record would reveal a virtual absence of the usual

Figure 12  
MZ TWINS

UNIT MAGNITUDE SPECTRA

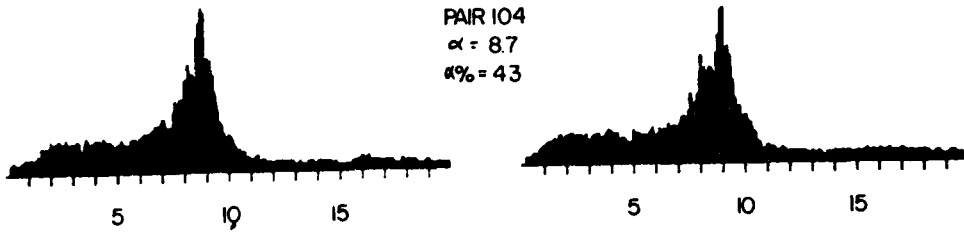
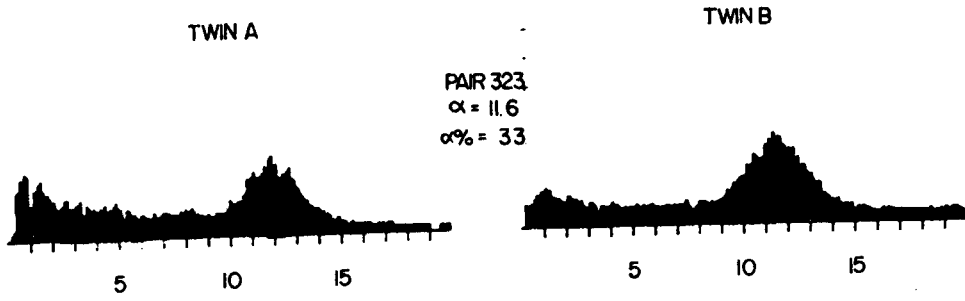
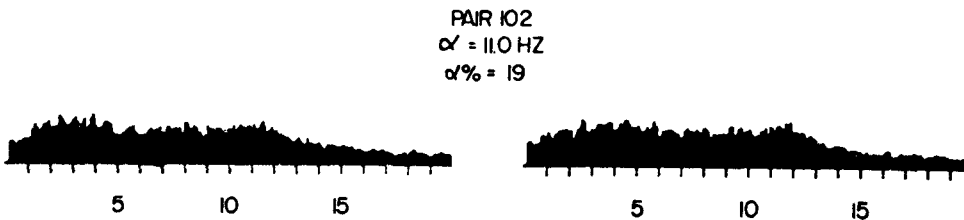
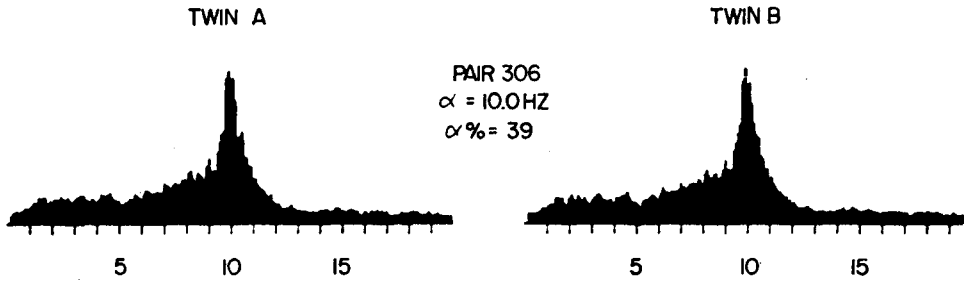


Figure 13  
MZ TWINS

UNIT MAGNITUDE SPECTRA



bursts or intervals of clear, sinusoidal alpha. Finally, Figure 14 shows a couple of MZ pairs who are real alpha generators. The pair on top, especially, produce tracings that look like nearly pure sinusoids; with a little amplification one could operate an electric clock from their EEGs and, geared up about 6 to 1, it would keep pretty good time.

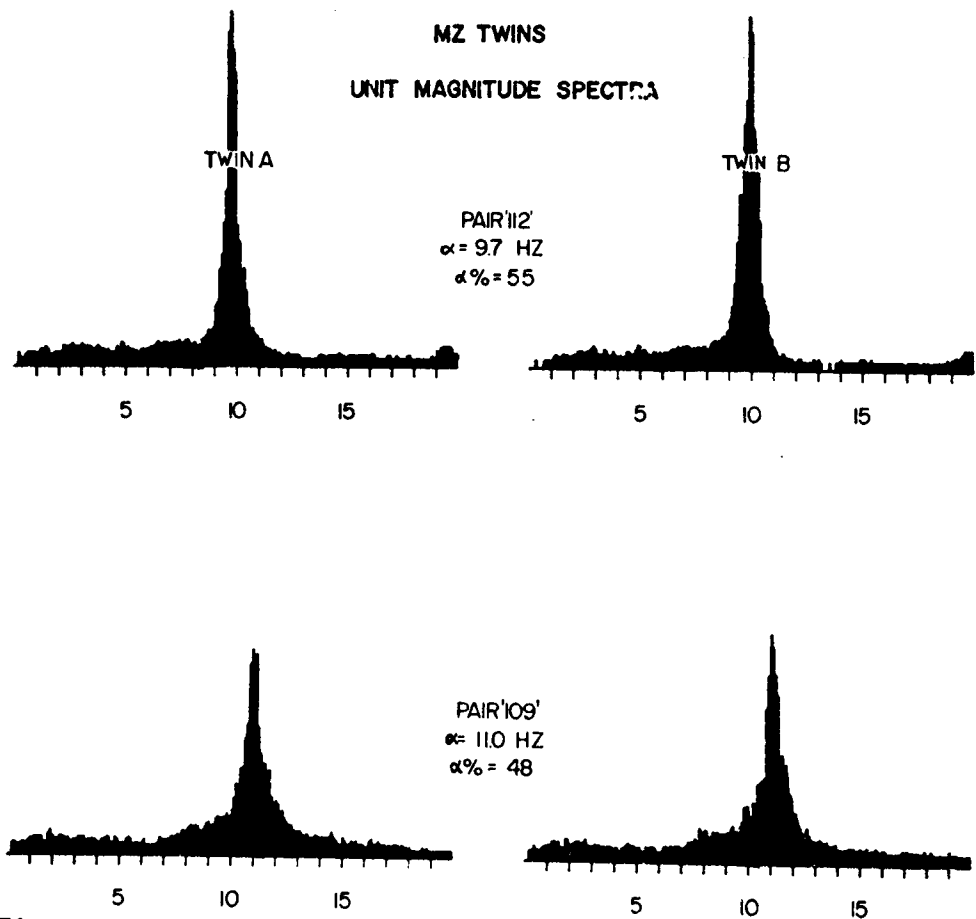


Figure 14

### Quantifying EEG Spectrum Similarity

The next task is to devise some quantitative index of spectrum similarity and a number of possibilities present themselves. Psychologists tend to think first of the correlation coefficient whenever an index of anything is wanted and one can, of course, compute a correlation between the envelopes of two spectra. The trouble is that spectra in general have a similar shape so that the correlation between any two spectra taken at random tends to average .5 or .6 rather than zero. Another, related, possibility is to compute the mean of the absolute values of the differences between corresponding ordinates. Since we had two spectra for each individual we could use this method to compare each twin with his co-twin twice and also each twin with himself. The ratio of the mean within-pair difference to the mean within-individual difference gives an index which is equal to unity when the twin's spectra are as much like each other as they are like themselves over time. For 35 of our 39 MZ pairs, this index proved to be less than 1.5 while it was greater than 1.6 for 21 of 27 DZ pairs, a hit-rate of 85 percent. A judge who merely sorts the pairs of spectra for similarity to the eye and then classifies the 39 most similar pairs as "MZ" will get at least 90 percent "hits." Still another method is to divide each spectrum into 10 adjacent 2-Hz bands and compute the proportion of the total spectrum in each band. These ten numbers can then be entered into a discriminant function analysis ---

actually, the absolute values of the 10 within-pair differences serve as the variables of the function --- with the result that 4 of 27 DZ pairs and only 1 of 39 MZ pairs are misclassified, a hit-rate of 92%.

In this connection, it is worth remembering that no variable, no matter how completely determined by the genes, can be expected to produce perfect segregation of MZ from DZ twins. Figure 15 shows the idealized distributions one might expect from plotting the absolute

IDEALISED DISTRIBUTIONS OF (ABSOLUTE)  
INTRA-PAIR DIFFERENCES ON ANY  
HERITABLE TRAITS

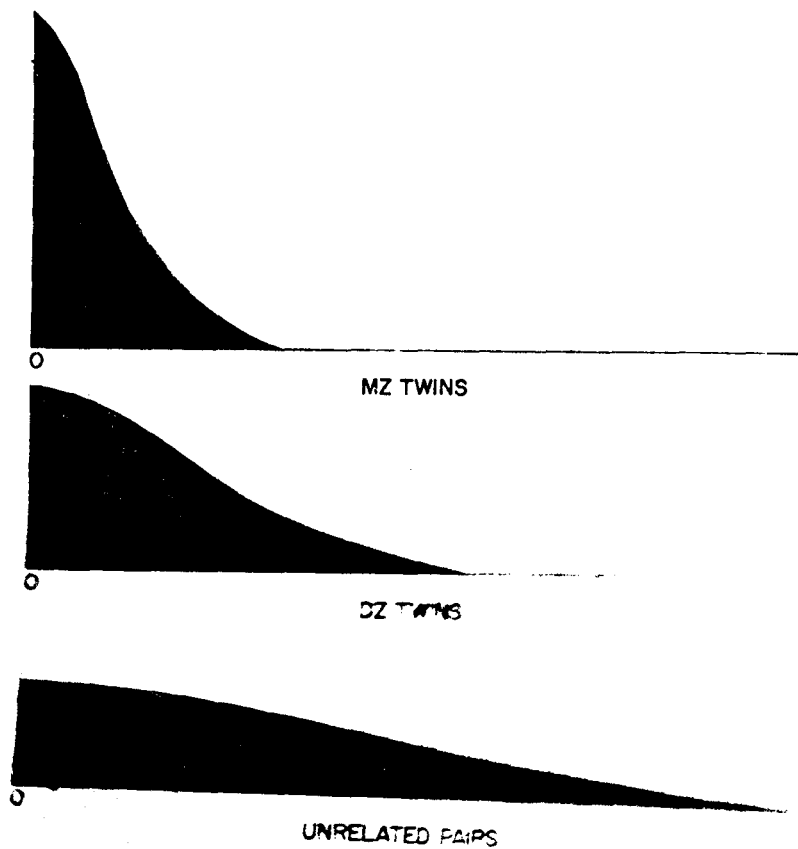


Figure 15



values of within-pair differences on even a completely heritable trait. Clearly, even two unrelated persons off the street might happen to have identical heights or IQs or EEG spectra and one must expect that a few DZ or even unrelated pairs will sometimes prove to be so similar as to be misclassified "identical." Moreover, one should keep in mind that DZ twins "have 50 percent of their genes in common" only on the average; some fraternal pairs may chance to be no more similar genetically than people paired at random while others may have nearly all their genes in common.

Returning now to the problem of quantifying "similarity of spectra," a basic question we could ask is, "How many independent dimensions are required to adequately characterize a spectrum?" In the discriminant function referred to earlier, we used the 10 2-Hz bands as variables but that choice was entirely arbitrary. These spectra really consist of an ordered set of 200 numbers, the 200 ordinates at 0.1 Hz intervals from zero to 19.9 Hz. A psychometrist might think of a spectrum as a set of scores on a battery of 200 correlated tests. He might also think of factor analyzing those scores in order to determine non-arbitrarily how many independent dimensions are required to characterize a spectrum. We have invested a large amount of computer time in analyses of this kind and I have no intention of burdening you with the details of this effort. As I have commented elsewhere (Lykken, 1971), factor analysis is best regarded as an exploratory technique, better suited to suggesting ideas than to answering questions in any final way. Quite consistently we find that about 80% of the variance (and more than 90% of the common

variance) in these spectra can be accounted for with only four to six orthogonal factors. Also quite consistently, it appears natural to identify one of these factors with activity above 13 Hz, i.e., what is classically referred to as Beta activity. Another recurrent theme is the co-variation of activity from 2.0 to 7.9 Hz, i.e., roughly corresponding to the classic Theta band. We could probably claim a Delta factor as well, especially if we were to include a higher proportion of sleepy spectra. The remaining factors represent very narrow segments of the classic Alpha band or, when we analyze the standardized spectra, bipolar factors which contrast, e.g., 8 Hz with 10 Hz or 9 Hz with 11 Hz. One model which might produce such results would be a variable Alpha generator having three parameters, amplitude, center frequency and variability. That is, we postulate a process, situated perhaps in the thalamus (cf. Andersen and Andersson 1968) which generates activity of amount Alpha, varying about a central, peak frequency which we call Phi. The third parameter, Kappa, measures the kurtosis of this distribution of frequencies, that is, whether the given quantity of alpha activity is concentrated near the central frequency or is rather spread out over a range of several Hertz, giving a broad, flat distribution. Specifically, we define Kappa as the ratio of the amount of activity in a 0.5 Hz band centered on Phi to the average amount in the two adjacent 1 1/4 Hz bands which form the shoulders of the "alpha bump." All three parameters vary from one brain to another with the center frequency, Phi, ranging from a low of about 7 Hz to a high of perhaps 13 Hz in our data. Alpha quantity varies from about 18% in

a flat spectrum to a high of over 60% while Kappa runs from about 1.0 to a high of over 30.0 in the kind of subjects whose brains could run clocks.

In other words, we find that we can account for at least 80 percent of the variance in our spectra with just five slightly correlated parameters (classic Beta and Theta, Alpha quantity, mean alpha frequency or Phi, and the variability of alpha frequency or Kappa), with classic Delta probably also being strong enough to be useful. Our kind of analysis cannot prove that these particular six factors are the best solution to the rotation problem --- that these six parameters correspond to six discrete processes in the brain --- but they do seem to comprise an adequate and convenient minimum statement of the information that is in a magnitude spectrum. Moreover, these six parameters allow us to compute heritabilities in the usual way, as well as correlations with other variables.

Table I shows some of these data. Body height and weight, as would be expected, show intra-class correlations greater than .9 for the MZ twins with values about half that size for the DZs. The F-ratio of within-pair variances for DZs over MZs is fairly large and highly significant for both variables. Mean heart-rate taken during the same rest period when EEG was being analyzed, shows a barely significant F-value and it can be seen that the intra-class correlation for the DZ sample is too low. Apart from ordinary sampling error, the only way I can think of to account for the DZ correlation being less than half as large as the MZ value would be to assume that common environmental

Table 1  
Intra-Class Correlations and Heritabilities

	$R_{mz}$	$R_{dz}$	$H^2$	$F_{(w)}$	P
Height	.91	.54	.76	3.22	.001
Weight	.93	.48	.90	5.22	.0001
Heart Rate	.67	.20	(.67)	1.97	.05
High school Rank	.86	.67	.37	1.99	.05
ACT Score	.85	.19	(.85)	3.10	.001
Delta	.76	-.01	(.76)	5.62	.0001
Theta	.86	-.03	(.86)	6.40	.0001
Beta	.82	.15	(.82)	4.09	.001
Alpha	.82	-.20	(.82)	5.65	.0001
Phi	.84	.21	(.84)	6.09	.0001
Kappa	.83	.23	(.83)	7.22	.0001
ER (Neuroticism)	.53	.39	.29	1.41	(ns)
LC (Extraversion)	.57	.17	(.57)	2.23	.05
Rod & Frame	.68	.18	(.68)	2.91	.01
APQ	.72	.28	(.72)	3.52	.001
Hypn. Suscept.	.48	.23	(.48)	2.14	.05

experience works to increase trait similarity for MZs, as is usually postulated, but that common experience acts to decrease similarity for DZ twins. Such a speculation might not be unreasonable in the case of, say, Extraversion, where our results are similar as can be seen in the Table. That is, one can imagine that same-sex fraternal twins might tend to form a sort of complementary relationship: "He's the extravert

so I must be the introvert," whereas an identical twin might reason, "He's extraverted so I must be extraverted too." Admittedly, this line of thinking is a bit strained when applied to physiological variables, although it is conceivable, for example, when DZ pairs are confronted together by some stress situation, that one member of the pair commonly feels more responsibility for coping while the other feels more relaxed than he would if his twin wasn't with him. It may be, of course, that our DZ sample is simply peculiar for some reason but Monte Buchsbaum, who is doing a rather similar twin study at NIMH, tells me that they also have been getting very low DZ correlations on some variables. In any case, these low DZ values yield heritability estimates which are spuriously high. Therefore, wherever  $H^2$  proved to be actually larger than the MZ correlation itself, I have listed the latter in parentheses in Table I as a sort of upper-bound estimate of the proportion of variance attributable to the genes.

Continuing down the table, an achievement measurement like High School Rank gives fairly high correlations in the DZ group and therefore very modest heritability. ACT scores, on the other hand, have a much higher loading on general intelligence and, for these students none of whom come from really deprived backgrounds, most of the variance in IQ seems to be genetic in origin. Again, however, the DZ correlation is inexplicably low.

The six spectrum variables all show MZ intra-class correlations of around .80 and negligible DZ correlations. The F-ratios are all highly significant and it is clear that all six components of the spectrum are strongly genetically determined although again the DZ correlations remain unaccounted for. Finally, just out of curiosity, I have listed some values for certain personality test variables which may be of interest. Neuroticism, as measured by Block's Ego Resiliency Scale, shows modest correlations in both twin groups and therefore a low heritability. Extraversion, based on Block's Ego Control Scale, seems to owe about half its variance to genetic factors; similar findings have been reported by others. On the portable Rod & Frame Test, we find that MZs are quite similar in respect to Field Dependency while, again, the DZs are discrepant. Both the Rod & Frame and my anxiety reactivity scale, called the APQ, have heritabilities well over .50, if these results can be believed, a considerably stronger degree of genetic influence than I have seen perviously reported for personality trait measures. Finally, our study indicated a very modest heritability for that mysterious trait, Hypnotic Susceptibility, with which no other trait has yet been found to correlate as much as .50; our findings here comport very well with the results from a large twin study done recently at Hilgard's laboratory by Morgan (1972) who reports MZ and DZ correlations of .56 and .18, respectively.

## Psychological Correlates of Spectrum Parameters

Summarizing thus far, we have tried to show how the frequency characteristics of an EEG sample can be conveniently represented in a magnitude spectrum, and that the salient features of most spectra can be quantified in terms of just six parameters. We have demonstrated the strong heritability of these spectrum parameters and these same data also indicate that spectra are relatively stable over at least one hour's time. It's interesting, incidentally, to ask one's self the following question: Suppose we were to re-test our twins under similar conditions a week or a month later, only to find that these parameters had low re-test reliability over such longer periods? That is, what can we infer about a trait which gives high heritabilities when the twins are measured concurrently but which also shows considerable within-subject variation over time? One can imagine that a measure of "state anxiety" might behave in such a fashion. We assume that a subject's current anxiety level is a kind of product of his "trait anxiety" on the one hand --- his constitutional level of anxiety reactivity, which may be a stable parameter of temperament --- multiplied by the immediate environmental press. To the extent that our twins tend to share the same experiences, to move through the same period of stress concurrently, then their "state anxiety" at any time will be similar to the extent that their "trait anxiety" or "anxiety IQ" is similar. Therefore, if "trait anxiety" is determined by the genes, MZ twins ---

at least student-age twins like ours who are still living and doing things together --- will tend to be "state anxious" at the same time, although their level of anxiety may be unpredictably different at some other time of testing. This illustrates another possible virtue of using twins in psychological research; normally we tend to be unenthusiastic about measures which have poor re-test reliability but clearly we should pay more respect to such a measure if it does at least show high within-twin correlations.

Two small studies we have done with singletons, however, indicate that most EEG spectrum variables are in fact quite stable over periods of weeks, giving re-test correlations of .60 to about .85. Having reached this point, it would be delightful if I could proceed to demonstrate to you what these quantitative, stable, heritable variables mean psychologically, these brain processes that we can observe through the window provided by the EEG. Figure 16, for example, shows the spectra of two more pair of DZ twins, selected for their interesting dissimilarity. Those four shapes represent stable, genetically determined differences in the functioning of these four brains; surely there are important and interesting psychological differences correlated with them? Alas, we haven't found them yet (nor has anyone else, to my knowledge) but on the other hand we have only started to look. Twins scoring high on a global intelligence test like the ACT do not differ consistently in spectrum properties from those who have low scores. Our measures of neuroticism, extraversion, anxiety



DZ TWINS  
UNIT MAGNITUDE SPECTRA

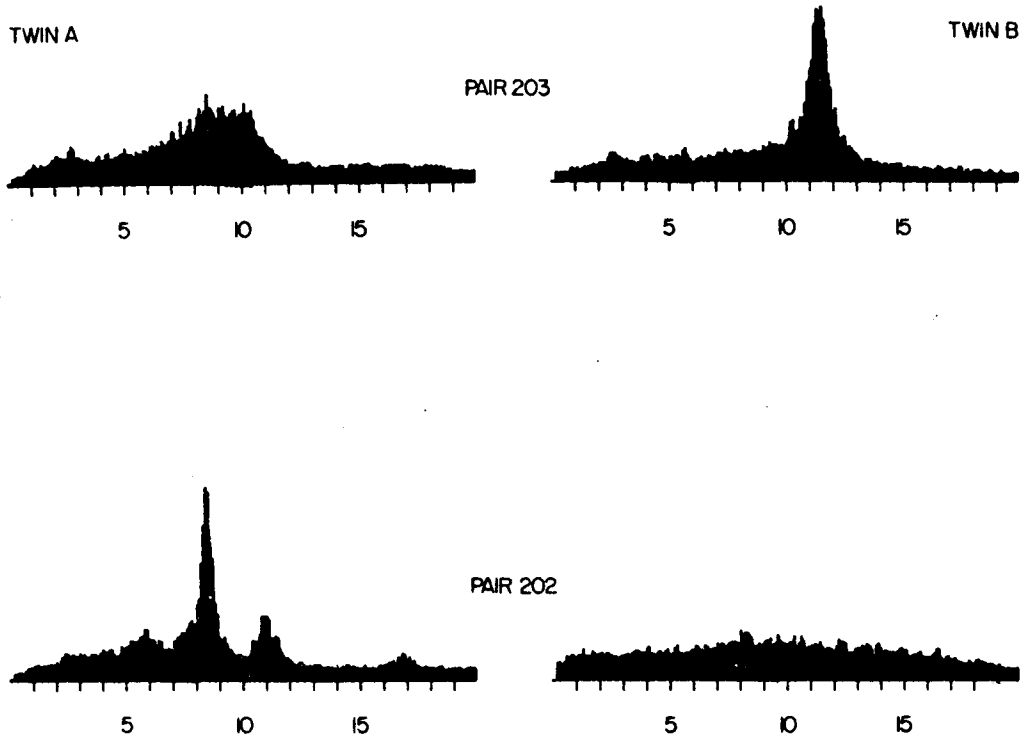


Figure 16

reactivity and field dependence do not show any striking correlations with spectrum variables. Maybe nothing does that is of psychological interest and the whole exercise has been a waste of time. I don't believe it but we shall see.

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