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RECENT DEVELOPMENTS IN ELECTROENCEPHALOGRAPHIC TECHNIQUES

DISCUSSION

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RECENT DEVELOPMENTS IN ELECTROENCEPHALOGRAPHIC TECHNIQUES

DISCUSSION

JOHN C. LILLY (Bethesda, Md.):

The program committee has given me an impossible task: in 5 minutes they want me to comment on the preceding papers and to present my own work. In that time I can do justice to no one's work including my own. Having launched this apology let us hurry through that which I do want to tell you in this short time.

As is amply attested by the references (1, 2) our technique of recording has been published previously. Let me start you off right by saying that despite the name of this Symposium, we are not doing EEGs at all; this fact is important to remember, even Walter forgets it from time to time.

Our technique (1) consists in recording the electrical activity at the cortical surface by means of an array of 25 electrodes in a square 5 x 5, obtaining simultaneous records from 25 amplifiers and 25 gas-discharge glow tubes in a square array by means of a motion picture camera. We implant the electrode array over a 1.0 cm.^{2} area of cortex. The amplifiers compute the average potential of all electrodes and deliver 25 signals which are each the difference from this mean value. The glow tubes with zero signal are held at a certain value of light output: relative positive signals decrease and negative signals increase the intensity below and above the zero level in a monotonic fashion. The motion picture camera takes photographs of the square light-array at a rate of 128 frames per second. Thus, if something electrical moves over the cortex we see it as something in light and shade moving over the array of lights. It is on such records that we labor, reconstructing a reasonable facsimile of what caused the record (Figure 14).

Maybe the following is what the committee had in mind when calling me in: that, somehow, the problem of investigating 1 cm.^{2} of cortex with a multiple-electrode array is similar to that of investigating the whole scalp with multiple electrodes. Maybe it is or is not similar: what Walter and Knott have told us makes it look, at first, very different; what Dawson has told us hints that there are similarities; what Rémond would have told us bears out the similarities.

To summarize the dissimilarities, in our work on the small cortical area, the frequency and phase variables, so dear to EEG hearts, no longer take the important place. With a neurophysiologist's bias, we immerse frequency and phase in a bucket of other variables: the growth and die-away velocities and loci of travel of cortical figures (3); and the statistical frequencies of participation of extent, of duration, of birth, and of death of cortical figures at given loci (4, 5). We also deal with the history of the form of the figures in space and in the electrical dimension (6). One instant in the life of one such

[1] Lilly, J. C. A method of recording the moving electrical potential gradients in the brain: the 25 channel Bavatron and electro-iconograms. *AIEE-IRE Conf. on Electronics in Nucleonics and Medicine (S-33)*, New York. Amer. Inst. of Electr. Eng., **1950**, 37-43.

[2] Lilly, J. C. Forms and figures in the electrical activity seen at the surface of the cerebral cortex. *The Biology of Mental Health and Disease,* Paul B. Hoeber, **1952**, 206-219.

[3] Lilly, J. C. Instantaneous relations between the activities of closely-spaced zones on the cerebral cortex: electrical figures during responses and spontaneous activity. *Amer. J. Physiol.*, **1953**, (in press).

[4] Lilly, J. C. and Cherry, R. B. Surface movements of click responses from the acoustic cerebral cortex of the cat: the leading and the trailing edges of a response figure. *J. Neurophysiol.*, **1954**.

[5] Lilly, J. C. and Cherry, R. B. Surface movements of figures in the spontaneous activity of anesthetized cerebral cortex: the leading and the trailing edges, **1954**, (in preparation).

[6] Lilly, J. C. and Cherry, R. B. Instantaneous potential gradients on the cerebral cortex: the three-dimensional structure of electrical figures. **1954**, (in preparation).

cortical figure is shown in Figure 14. Thus we are dealing with the macromicroscopic anatomy of those relatively tiny things which make up what one sees at a single scalp electrode: the scalp electrode sees the general trends, the superposed resultants, of the crowds of cortical figures we see in a small area of cortex. In EEG frequency and phase analysis, one analyzes in and correlates between relatively large areas the superposed events of these crowds. Maybe some day we can bring these now disparate areas of investigation together to show the more complete picture.

Brazier has with other activities (7), we will be closer together in method. Rémond's method of showing the position of amplitude lines on the scalp is close to our methodology; but his is a neat way of avoiding some of the laborious calculations which we must do. If Rémond can extend the method to many more electrodes and make it faster, we will be happier about the results.

In Walter's latest instrument, frequency and phase computations are built-in: but, as he points out, the rotating arm of light on his cathode ray tubes can be speeded up so that he sees somewhat the same thing as we

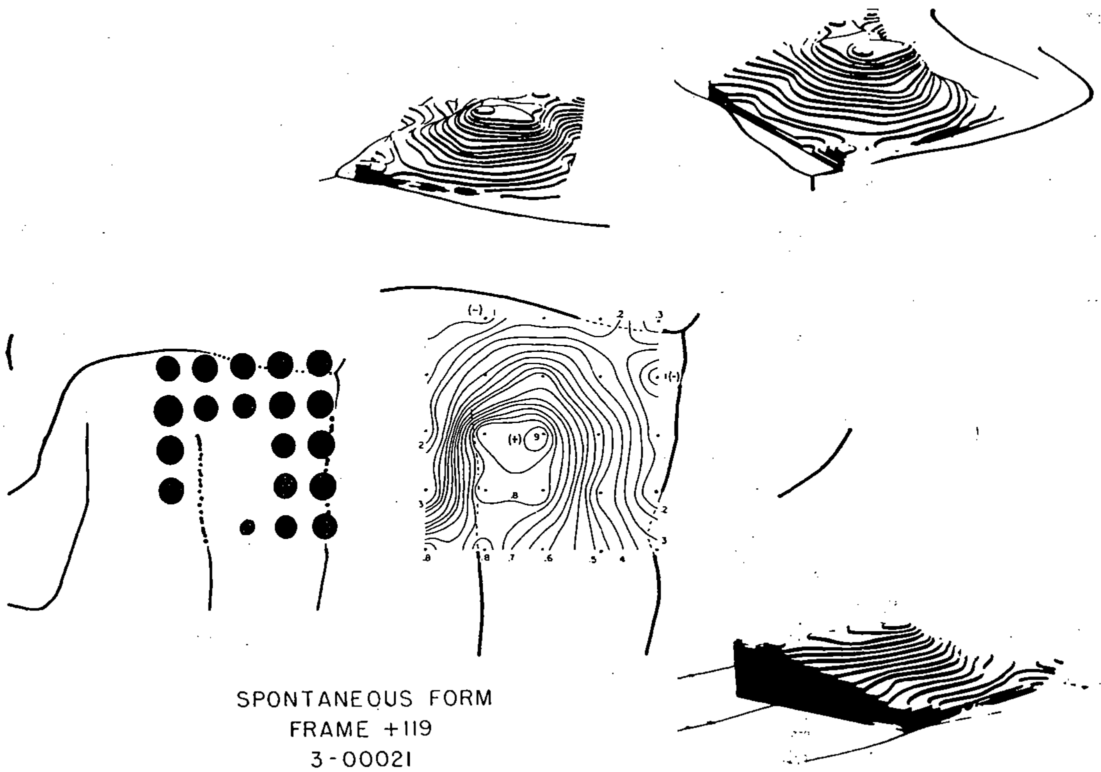

Fig. 14
One phase of the development of a cortical figure in an anesthetized cat.

In summarizing the similarities, we have Dawson's technique, which consists of finding in a "noisy" background the familiar evoked responses of the neurophysiologist: if he extends his treatment to 2 dimensions of space on the scalp, in somewhat the way see with our technique. I would be happier with more electrodes, amplifiers, cathode ray tubes, closer packing of his cathode ray tubes,

[7] Brazier, M. A. B. A study of the electrical fields at the surface of the head. *EEG Clin. Neurophysiol.*, **1949**, Suppl. *2*: 38-52.

and high speed movies of the output field: but, of course, I am biased by my own results.

These are a few of the similarities and dissimilarities between the small-area-of-cortex view and the scalp view as represented by past work. As for the future, I am incorrigibly optimistic; there are signs that eventually we will all have enough electrodes recording adequately from scalp, cortex or subcortex and displayed simply enough to be quickly understandable, so that we all will be happy. If this comes about, I am sure that what at present look like divergent points of view will be seen to be merely a stage in the scientific development of each of us on our way to understanding what really goes on in the brain.

This phase of a spontaneous figure in the electrical activity is taken from a motion picture record of many such phases for the same figure. A high contrast print of an original frame of the record is shown on a brain diagram on the left. Each frame of the original record of the light images was measured by a photocell technique, and an equipotential contour map was constructed by linear interpolation from these data; one such map is shown above, plotted on the posterior ectosylvian gyrus of the cat. From the equipotential map, a 3-dimensional model was constructed from lucite sheets; the model is seen in three different views placed at each viewing angle around the contour map. Zero potential difference is at about the line labelled 0.5 on the contour map; the large main peak is relatively surface positive. Forms like this one are characteristic of this area of the cat's cortex; they move over the posterior ectosylvian gyrus in paths which have been mapped and statistically defined (5).

W. McCulloch:

Inasmuch as Rémond is not here, but as Dr. Frank Offner has been collaborating in most of what he would have said, I am going to ask him to present to you, rather briefly, a description of the work done by Rémond.

F. Offner (Chicago, Ill.):

Various speakers today have presented several fundamentally new or different methods for electroencephalography and for presenting EEG data. I think that it is interesting for us in America to note that all these new methods: Walter's first toposcope, his frequency analyzer, and the analyzing toposcope, and also, now, the method of integrating responses presented by Dawson have come from Europe; and what I am going to briefly present here, also came from France, for it is based on the ideas of Dr. Rémond. When he was here last year, I was fortunate enough to collaborate with him.

These methods of frequency presentation mostly have been to present the time function: i.e., the variation of the EEG at a point. Now, the method of Dr. Walter's allows you to see, also, the time variation at various points; that is, it gives simultaneous analysis of the time course of the variation of potentials at several points. Dr. Rémond wanted to record, on the other hand, the spatial variations of potential at a given time.

In this, and all these other methods, no data are actually obtained which are not inherently present in any type of EEG recording; that is, the ink record or the oscillographic recordings; still they are techniques by which the data may be more readily interpreted. The method he devised for doing this was fundamentally very simple. Assume a sequence of alpha waves through multichannel recording from a series of 8 electrodes in an A-P line over the head. A vertical line drawn through any point will intersect each wave in the different channels simultaneously although at a slightly different point on the wave. Then, if these several points are replotted, and if there are enough such points, the spatial distribution of the wave can be reconstructed for any given instant.

All of this apparatus was designed to clock the contours of such potentials. Each EEG channel was sampled 60 times per second. This voltage sample was fed into a storage circuit, and for convenience in presentation, the voltage converted into time.

Time is then shown as a length of line, and when these several lines are plotted (automatically) their overall contour yields a plot of the potential across the scalp. The sequence is repeated at 60 times each second, and shows how space waves travel across the surface of the head.

I think that presents the method. Dr. Rémond has published his preliminary results [1].

W. McCulloch:

Would Dr. Norbert Wiener be so kind as to open the discussion, because he, probably more than any living man, knows more about the analyses of sequences in time.

N. Wiener (Cambridge, Mass.):

I should prefer that Dr. Brazier present the material, and then I will be glad to say a few words in discussion.

W. McCulloch:

Dr. Brazier, may we hear from you at this time ?

Mary A. B. Brazier (Boston, Mass.):

There is a group of us here in Cambridge and Boston who have been working together on the problems of correlation. As this is a very difficult method to present in technical detail, I would like to extend an invitation for any one who is interested to see the correlator we are using. This will be demonstrated by my colleague, Dr. Barlow, in Dr. Rosenblith's laboratory at the Massachusetts Institute of Technology during the period of the Congress.

Dr. Dawson has told us a good deal about the kind of information that he would expect to find from this method by crosscorrelating the EEG with an imposed stimulus, and I would now like to draw your attention to some work on the so-called "spontaneous" EEG. At the top of this slide (Figure 15) is shown the autocorrelation of a unipolar recording from the right occipital region of a patient. It very clearly shows the long-lasting periodic quality of this EEG. This is a correlogram of a 1 minute recording of the EEG delayed out in 10 msec. steps to 1 second. Beneath it is a 10 second sample of the automatic frequency analysis run simultaneously, together with the original EEG trace.

The second correlogram shown is the crosscorrelation between the occipital and parietal recordings run simultaneously. Again the same frequency is seen but you will also notice that there is a clear phase displacement. This information about phase was not available to us by the other techniques we were using in our analysis of these data.

A great deal more information is really available from the correlation type of analysis, and I think we would all be grateful if Dr. Wiener would be willing to discuss some of its implications for electroencephalography.

N. Wiener:

I would like to have that slide left on. One of the interesting features is that this is a multiple correlation. At the top of this slide you have a potential in the brain from a particular spot multiplied by the same potential after each of a series of delay times. The horizontal coordinate is the delay. The vertical coordinate is the product of the potentials, averaged over a considerable time. Each pen excursion represents the value of this product at a specific delay time. When you look at the original graph from which it came, you see clearly that it was a 9 per second oscillation. You note almost nothing else.

Please notice in the correlogram that the upper part of the curve oscillates at 9 per second, and that the amplitude of it, correlated with itself is, at the beginning, not more than 4 to 5 times what you get after one second. In other words, you have a remarkably slowly decreasing consistency of this oscillation over a delay time as long as a second, and probably you will have an observable consistency over two or three seconds. That is, this result shows that the instrument has not been working over a long enough time to give full results, and that it would have

[1] Rémond, A. and Offner, F. Etudes Topographiques de l'Activité EEG de la Région Occipitale. *Revue Neurologique,* **1952**, *87*: 1-8.

been profitable to extend the analysis to even longer delay times, had the instrument been able to do this.

Next, there is in this series of Dr. Brazier's the harmonic analysis as shown in the correlogram. The effect of harmonic analysis on correlation is to give the square of the harmonic analysis of the original phenomena.

Here, I have to be a little careful. I don't feel clear as to how harmonic analysis has been explained to you in the case of continuing phenomena. What happens is that when you take a harmonic analysis of a continuing phenomenon, you have a discrete part of the spectrum, and a continuous one. Those are not at all easy to see unless you go through a very careful mathematical process. What you see here is that obviously when you make a harmonic analysis, you get something that looks like a very narrow band centering at 9 per second. Everything else will be very much mixed.

If you would take the squared oscillating part of the curve and analyze it directly, you would find that the modulation of the sine oscillation determines a part of the autocorrelation. If you take the modulation on a wave, and add to the wave itself something like the modulation, you will find a central band of the same frequency as the modulation, plus modulated waves centering about the side bands of the 9 per second frequency. Those side bands show in the analysis. The interesting thing is that those side bands could be easily interpreted as independent rhythms. They really aren't there in any important sense at all.

Notice that the left line of the diagram in the case of zero time displacement goes through the middle of the peak. In the case of crosscorrelation it goes to the side. It would be easily possible to determine the displacement of the left line, to the second line, with respect to the middle, there (indicating on slide), to within perhaps one-tenth, perhaps a nintieth or one-hundredth of a second. This means that we have an excellent way of examining relative phases of brain waves at different points.

Now, that should be combined with the sort of work reported by Dr. Lilly, because it must play a role in what we see in the case of a moving pattern. Such a pattern will have to continue in some sense over a large number of oscillations. One important difference between Dr. Lilly's work and that shown from the Massachusetts General Hospital, is that in Dr. Lilly's paper, the oscillations were forced oscillations and did not have this long sweep of the spontaneous oscillations.

The extraordinary thing in the Massachusetts General Hospital observations is the persistency of phase. This persistence has another property which has declared itself strongly; namely, it seems very closely parallel to what you might expect in the case of flicker. You couldn't have any piling up of effects over a long time *a priori*. Assuming that the brain has a good memory for phase, if you were to stimulate it at the peak of each of a sequence of regularly spaced oscillations, you could build up with very small individual stimuli to a large stimulation. It is only such a regular memory of the brain for phase that is consistent with the data of flicker stimulation with its long piling up of separate pushes.

Now, this long duration could not be expected to show itself clearly if it did not show up also in the case of harmonic analysis of spontaneous phenomena.

Now, you have here your 9 per second band, very narrow and very sharp. If you spread it by a considerable ambiguity in phase, it will become much lower. Notice, there will be nothing that shows clearly in that case, and the spectral crosscorrelation picture will not show consistent waves for large displacement.

Now, I want to say something about the mathematical-physical analogues of this method to show what you are doing. The use of the interferometer is well understood in optics, and it is closely related to harmonic analysis by autocorrelation. As a matter of fact, any correct theory of harmonic analysis, plus the use of correlograms will give a treatment of spectra which I discussed as far back as 1929. I published a previous paper on this theme in 1928, and developed a rigorous theory of continuous spectrum.

Do you remember how Michelson determined the distances of the stars ? He took two mirrors, one-hundred feet apart, and took light from the same star. He made these interfere, producing a series of concentric interference bands. He determined how long it was before the bands disappeared. The more quickly they decreased the greater the distance of the stars.

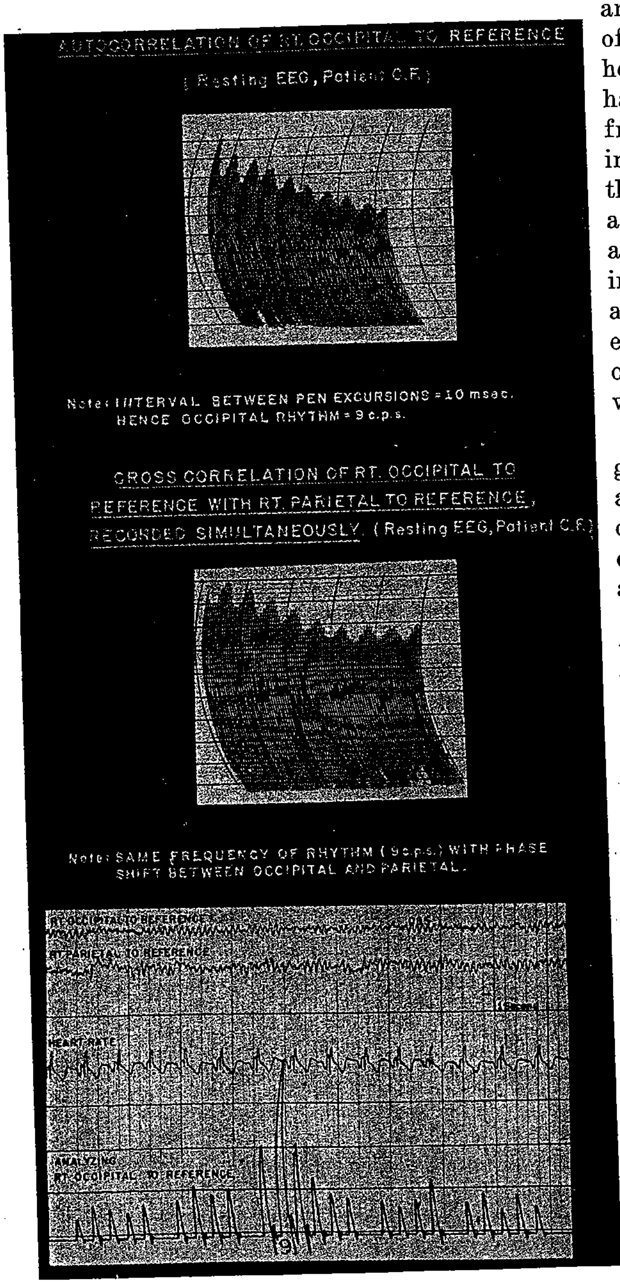

Fig. 15

The correlogram (Figure 15) is a close analogue of the interferometer, in time instead of in space, and the long distance that it takes here for the bands of oscillation to die out have a similar significance. The smaller the frequency band is, the longer it takes for the interference oscillation to die out. That is, this is an ultra-refined method of harmonic analysis. The ordinary methods of harmonic analysis are more like the telescope than the interferometer methods of examining stars, and the result is that you do not get the extremely intense subdivision of frequency over an extremely small frequency region that will be shown by the interferometer.

I expected when I first saw the correlogram, that the bands would not be as sharp as they are, that we would have two or three of these oscillations, and the oscillation would die out rapidly and be practically unobservable.

Another point is this. You will notice at the height of the peaks, above their base, it is very nearly proportional to the height of the base above the base of the whole picture.

Now, that, to me, is very significant. It suggests that a large part of what you see in the background of the picture is an effect that is due to the dying off with time of the influence of the signal wave itself, and that you are dealing with a rectifying phenomenon.

Otherwise, if the non-oscillating part of the correlogram were independent of the oscillating part, I would expect that the bases of the fluctuations would be nearly horizontal, and not roughly proportionate to the level of the fluctuations themselves.

I think that there is a lot more work to be done.

You can get the time difference between the action of the different parts of the brain, by the crosscorrelations taken. There is still more to be done by which we can use phenomena of this sort, to determine the amount and direction of causality and drive. It would take too long to go into this at the present time.

W. McCulloch:

May I take this opportunity to thank the official and unofficial but invited discussants, for opening the discussion. It is now open to the floor.

W. Grey Walter:

May I add something about observations made with the Rémond instrument? I was able to discuss these with Rémond, himself, in Paris, awhile ago, and it is a great pity that he is not with us now. I thought it might interest the audience to know something about the results.

In a short paper published in the Revue Neurologique, Rémond mentions something which intrigued me very much, in relation to what Professor Wiener has just said about flicker.

The Rémond instrument produces records showing the patterns of phase distribution in a set of scalp derivations. These are essentially cross sections with respect to space: the records indicate simultaneous differences in potential at different points over the head. Now, such records taken during spontaneous alpha activity, that is during rest, show a great deal of variation from time to time, even during a single alpha wave. On the other hand, records which Rémond has taken during photic stimulation show a remarkable stereotypy or constancy in the spread and distribution of the evoked potentials when the conditions of mentality and surroundings are, themselves, constant.

That is the first result that he has obtained, that there is a striking difference between the topology of evoked potentials and that of the spontaneous rhythms in the EEG.

These observations, combined with those previously described, suggest that the situation is more intricate than Professor Wiener has said; the effect of flicker is not just a disturbance of a steady rhythm. In fact, in many people, there is no relation at all between the optimum frequency for flicker stimulation and the frequency of the alpha rhythms. The effect of flicker stimulation does not seem to be related to the alpha frequencies in any simple way. The alpha rhythms act more as a gate, synchronising and distributing signals over a diversity of regions. The distribution of the evoked changes is not the same as that of the resting alpha rhythms; the two effects are interlaced, in a dynamic and rapidly changing pattern.

N. Wiener:

I should like to comment on that. The first thing is the regularity of the fluctuations of the correlogram. I would not expect to find spontaneous fluctuations in time any more than in space.

I have a strong suspicion that if one took the autocorrelation at different points in the record of "spontaneous" activity, one would find a greater pattern; although I am not sure, I suspect that very strongly.

That is one thing; the next thing is: I have already said there is a high degree of rectification in brain waves and that is shown in the relation between the base height and the height from the base to the top points of the correlogram. With that, we should expect that a change of dynamics of the brain would be associated with a change in the whole frequency of the oscillations.

The fact that the correlogram does have a consistency for a long time is probably associated with lastingly consistent dynamics of the EEG.

C. W. Darrow (Chicago, Ill.):

I would like to mention a piece of equipment for comparison of EEG's from different areas which my colleague, Dr. G. P. Arnott, and I have developed for research. It gives continuous, wave-by-wave indication of phase differences and of in-phase relative magnitude.

Previously, in order to study the phase relations between areas, we drew ordinates through either the peaks or the valleys of waves from different brain areas. Either surface positive or surface negative waves could be compared by this method, not both at the same time. In similar fashion an automatic device to provide such an analysis may compare either surface positive or surface negative aspects of the EEG, disregarding the other half of the wave pattern. Arrangements were made to short-circuit or by-pass either the positive or negative half of a fraction of the EEG outputs of different channels. Simple bipolar combination and comparison of pairs of these simplified patterns gives us wave by wave indication of inter-area phase differences and relative magnitude of in-phase waves.

If we compare from any two channels half-waves which are simultaneously equal and in-phase, they cancel. If two waves are simultaneous and one larger than the other, the direction of the potential difference between them will indicate which is the larger. If, on the other hand, the half wave in one channel is leading or lagging a corresponding wave in the other, the result is a diphasic pattern indicating the time relationship. Thus the device gives a continuous wave by wave indication of phase relations, and of relative magnitude of in-phase differences, unobscured and unconfused by integration.

If anyone is interested in the results of this type of recording, I have some samples available.

W. McCulloch:

That brings up one point that I should like to emphasize. It is obviously impossible for anybody seeing a device of this kind for the first time really to understand more than literally what is said to him about it, — if he can understand that much.

I saw it first, or I saw the beginnings of it two years ago, so it was not new to me, and when I saw it again, I began to get a grip on what it was actually doing.

N. Wiener:

The method of determining the period by measuring bottoms and tops is essentially not a good method. It is no good when random oscillations mask small but extremely consistent ones.

J. L. O'Leary (St. Louis, Mo.):

From the description of Rémond's technique, it seems to me that it depends on corresponding phase relationships over an area; otherwise would not different phase relationships as recorded from spatially separate electrodes give the appearance of different cross-sections of the alpha wave ?

W. McCulloch:

Were your records obtained instantaneously and simultaneously from all these points ?

F. Offner:

Yes, the gate opens simultaneously on all channels.

J. L. O'Leary:

On frequency changes, do you record consistently ? On the successive storage for each alpha wave, are you storing at exactly the same point of the cycle ?

F. Offner:

No. We attempt to record fast enough that we catch many phases of each alpha wave; we don't try to catch them at the peaks. If we record 60 times per second, we obtain six cross-sections of each alpha wave.

I think that the answer to Dr. Wiener's comment is that Dr. Darrow has obtained useful results, no matter what Dr. Wiener's mathematical analysis may indicate.

N. Wiener:

I should like to say this. As to the question of what happens in the case of changing frequency, you have to be precise. With a changing frequency, you will get no sharp frequency in the autocorrelation; not a sharp frequency, but a frequency band. This will show itself exactly as I have indicated, in that these oscillations will decrease in amplitude, go down, and change rapidly.

Now the remarkable thing is that in fact, not in theory, for it has nothing to do with theory, Dr. Walter has shown that they die out slowly, which means for that particular job the frequency does not show sudden oscillations.

W. A. ROSENBLITH (Cambridge, Mass.):

I have the feeling that we ought perhaps to look at some of the more general aspects of the discussion that is taking place here this afternoon. In spite of certain remarks, this has been a discussion of data reducing systems and not of different models of the brain. The data reach us at a rate that we can, unfortunately, not control and leave us with the problem of extracting something from them that will make sense.

Investigators have different primary interests that lead them to different operational requirements for the analysis of the data. However, I, at least, am afraid that this discussion may have produced the impression that the participants are hiding their brain models in their hip pockets when they should have checked them at the entrance. This is really not the case. What is happening, on the contrary, is that we are all groping for those kinds of generalizations, for those kinds of concepts that will permit us to collect more useful data in the future.

We have, for instance, been interested in using correlation techniques, since we are interested in certain problems in which evoked and spontaneous activities intertwine. If we record our stimuli (for instance, clicks) on one channel while at the same time recording electrical activity from various parts of the brain on other channels we can look at the events in terms of crosscorrelations. This analysis offers to us — for this problem — advantages that other methods do not possess. The fact that we are using a correlation technique should not make us blind to the fact that other methods may yield better results when other questions are asked. Investigators have in the past made progress without much electronic gear. The time has come, however, where the questions they ask cannot anymore be answered by just looking at an EEG record. We must learn to reduce the continuous output of the brain to a set of numbers or functions that will exhibit differential effects under appropriate changes in conditions.

Let us then remain aware that there is no "ideal" method of analysis, since there is probably no "ideal" question to be asked from nature. Under these circumstances, we will have to recognize that the success of a method of analysis will have to be here, as elsewhere, measured in terms of the size of the body of data it can encompass and perhaps even predict.

H. SHIPTON (Bristol, England):

Professor Wiener would not, necessarily, say that the other kind of analysis ought to be outlawed.

Something of what I was going to say has already been said, so I only need to make two rather prosaic remarks. This comment about iconoscopes of the kind described by Lilly is not intended to be a criticism of his method; but under certain conditions there would be a stroboscopic ambiguity, which we discovered early in our exepriments. It raises a question as to whether Dr. Lilly may have actually deliberately interrupted the current supply to his neon tubes, at controlled frequencies, in order to make the frequency devices sensitive, making some of the waves travel, perhaps, in other directions.

Referring to harmonic analysis, I express only surprise, but not comment, that nothing has been said about the use of the averager; that is to say, what is designated by the manufacturers as the averager.

A. FORBES (Cambridge, Mass.):

I am moved to raise the question whether, in all of this mathematical frequency analysis, we are not in danger of missing one of the basic, fundamental properties of nerve tissue, which is the explosive character of the nerve impulse.

Let us suppose a person, trained in terms of pendulums, harmonic cycles, alternating current, and so forth, observes a pendulum being made to swing in a period of one cycle per second. He might easily infer that it was being activated by a source of energy such as a slow AC, or something of that sort. In reality, it might be made to swing by having a pistol shot hit it once a second. This could give to a heavy pendulum a smooth sine-wave motion that would have nothing whatever to do with the time relations of the explosion of the cartridge in the pistol, or with the nature of its energy. In trying to analyze brain activity by picking out frequencies, we are in danger of thinking in terms of AC. We are likely to go off the track if we talk too much about frequency analysis on a mathematical basis, without bearing in mind that the electrical activity is an expression of electro-chemical disturbances.

J. C. Lilly:

In answer to Mr. Shipton's remarks, I would like to make the following comments.

We have had a lot of experience with illusions being generated by this type of output display. When one watches the display while it is connected to the animal, one sees lots of things that aren't coming from the animal's brain. There are circling movements and various other things that appear in the display; we have become used to discounting these illusory appearances.

We have found in recording at 64 frames a second that these illusions were also seen in the moving pictures; in fact, additional ones were generated by complex stroboscopic mechanisms.

We employed 128 frames per second and most of these illusions disappeared when looking at the records at 16 frames per second. Even 128 frames per second is not completely satisfactory: we plan to use higher recording speeds in the future.

W. Grey Walter:

Dr. Knott's review is truly remarkable for its scope, modesty and good humour; he deserves the highest praise for bringing the main points into relief as well as illuminating the shadows. I have several specific comments. Many of us have been seeking for years the "perfect" method of automatic analysis, but I fear this is a will o' the wisp. I do not agree that frequency multiplication as in the Grass analyzer is "the most accurate method which has ever been proposed." There are many sources of serious and subtle error in such devices; for example, a trace of rectification (non linearity) in the shadowgraph-photocell system or its equivalent will generate demodulation products. This means that, for example, a ten cycle rhythm which fluctuates in amplitude at about one cycle per second may give rise to spurious components with apparent frequencies the same as the *rate of fluctuation* of the higher frequency. Furthermore, the variable-frequency type of analyzer is hard to adjust for even-tempering of selectivity and sensitivity over the whole gamut of frequencies.

It seems impracticable to obtain analysis of frequencies and phases simultaneously and instantly with a direct write-out. The EEG patterns change fairly rapidly, so that we must suppose that in a reasonable epoch for frequency analysis — ten seconds or so — there is a wide range of phase-relations between components and between channels. The effect of this is that the phase indication over this period would be, at the best, the average of an average, at the worst, a random jumble of instrumental artifacts. We introduced the scanning vector into our toposcopes to provide the missing data on phase relations, and unfortunately we seem to need an automatic frequency analyzer, a phase indicating toposcope and a conventional recorder all working together to get significant information in a tractable form. The question of stability, calibration and maintenance is an awkward one because we have the oldest analyzer and it seems to give the least trouble; it is not very encouraging or helpful to say "the first ten years are the toughest." In our experience an analyzer needs no more attention than any other elaborate instrument: an hour a week should be sufficient.

As to performance and resolution, Dr. Knott has given a very fair picture. In the presence of truly random "white" noise a standard analyzer can indicate accurately rhythmic activity with an amplitude of about one twentieth that of the average noise level. One feature which Dr. Knott dealt with in less detail is the length of the integration epoch; our analyzers are fitted with averaging devices to provide a comparison between the results of short and long term analyses. This comparison gives a measure of EEG "versatility" which Janet Shipton has been comparing with psychological versatility. We had hoped to have some results to present here but we are not yet happy about the statistical treatment. One can say however that analytical data do lend themselves particularly well to statistical manipulation, and I think myself this is how analyzers should be used. Some mention should be made of the work of Ellis (who produced the Ediswan analyzer) and Last who have presented statistical charts [1] from analyses of EEGs from 100 normal subjects.

The analyzers we are discussing are not "harmonic" analyzers and in using them no assumption need be implied that the signals are sinusoidal. A regular series of transients will certainly be seen as a "harmonic" spectrum but I have pointed out elsewhere that spatial analysis often reveals that some of the transients seen in the EEG are in fact made up of several distinct components so frequency analysis can actually help to identify those components which are congruent, truly focal "spikes," and those which are really due to instrumental synthesis of several inter-related but distinct physiological events. Frequency analysis is only one way of processing EEG data — but just because it supplements without supplanting conventional methods I feel it is still the most convenient way of increasing resolution without narrowing the field of view.

B. G. Farley (Cambridge, Mass.):

I have a comment to make about instrumentation. Dr. Rosenblith has said that essentially, we are discussing two problems. One is to get the data, the other is to analyze it and do something with it. These problems occur in all sciences, but I think it is fair to say that analysis of the brain can bring in more data per unit time than any other science so far. The difficulty arises as to what to do with it.

I would like to invite your attention to the possibilities offered here by the very high speed digital computer. I refer particularly to its ability to accept large amounts of data as the data are produced, to perform any required analysis, and then to present the desired results oscillographically. As a matter of fact, it is not unrealistic to assume that we could present oscillographically more than one of these ingenious processes we have been hearing about today at the same time. Thus, since the computer is such a flexible tool, we can play with presentations or methods of analysis until we find the most useful.

A difficulty is, of course, that at present, digital computers are expensive. However, if sufficient interest is shown, I would hope that existing research computer centers may be persuaded to participate in such work.

J. Knott:

In responding to the interesting idea of developing an analyzer to analyze the analyzers, suggested by Dr. Farley, we have been interpreting most of our data from wave analyzers by visual methods of analysis. Our improvement in acuity is really only partial. I think that we need to clearly recognize this fact, and develop further techniques for increasing acuity.

It is a pleasure to have the thoughtful comments by Dr. Walter, and I am indebted to him for them. He has deftly touched on the significant points I have understood in other ways than he, and perhaps all that remains for me is to provide some clarification in my own mind.

His remarks about the Grass analyzer are very likely correct. He and I first discussed the demodulation problem seven years ago, at which time we independently arrived at the same conclusion. Unfortunately, it is impossible to test these hypotheses as the instrument is no longer extant. For this reason I hesitated to make such an explanatory note.

His remarks about phase are essentially identical to those I would now make, having

[1] Ellis, N. W. and Last, S. L. Analysis of the normal EEG. *Lancet,* **1953,** 264: 112-114.

viewed the toposcope, and having heard Dr. Walter's lucid explanation of its capabilities. When Mr. Shipton visited us recently I had opportunity to assess its potentialities and found them multiple. For certain types of problems this instrument is probably indispensable; for other types a frequency analyzer will prove to be indispensable; and for still others, both will be needed. Dr. Dawson's contributions will also find their unique place, where "Topsy and Annie" will not be adequate. My thought is that the technique should serve the problem, rather than the other way around.

If the first ten years are the toughest, I may shortly find myself out of the woods. Admittedly, many of the problems I have are of my own manufacture, but some are inherent in the technique as we now know it. I cannot help but view with alarm the use of any analyzer by a person unaware of the limitations his instrument may uniquely possess. My feeling is that all such instruments do have their limits. No analyzer should be used unless (or until) its stability is definitely known (first-hand), and unless adequate checks are made, relative to that stability — or instability —, of the gain, the sharpness and the frequency of each resonator-integrator unit. When Dr. Walter says that an hour a week will suffice for attention to an analyzer's needs, he of course means for *his* analyzer's needs; he certainly does not mean to generalize to *all* analyzers.

We have not worked with averagers for various reasons. Dr. Walter and his associates are able to speak as authorities on this topic as they have had the greatest experience. However, from the practical and clinical point of view, I would admit as evidence the experience of Gibbs, who used a long (30 second) scanning period, which should be comparable to averaging three 10-second epochs. Gibbs did not feel, at least relative to the problem of epilepsy, that his analyzer was of great clinical utility.

As I mentioned, the problem of using analyzers to study non-sinusoidal and transient inputs is one that seems to lead to considerable misunderstanding. Dr. Walter's additional comments are greatly appreciated and I hope will assist in laying some of the ghosts which seem to run rampant at meetings such as this one.

I would most whole-heartedly agree with Dr. Walter that frequency analysis is "the most convenient way of increasing resolution without narrowing the field of view." May I again reiterate that the narrowness or breadth of the field does not just depend on the analyzer, which is only an instrument capable of feeding information to a brain, but on the brain itself?

Christine Kris (Chicago, Ill.):

Whether electronic brains can be used to quantify the relationships between brain waves recorded simultaneously from different parts of the head is no longer a question, since there are now methods available for analysing even the currently existing ink-written records. There is an IBM machine called the Tele-Reader: it follows the penned deflections of a wave up and down. From it we get numbers. These are coded and fed by teletape into a digital computer.

We are currently doing an analysis on data collected from 171 patients, in fact, it has just been completed by a method similar to this. We happened to do it the mechanical way. The analysis of wave-forms is on ten second time samples, obtained from patients ranging in age from 5 to 50 years. Three to five samples are averaged from each, on 22 separate measures. Then standard scores are derived from the distributions of these measures and correlations computed. On Illiac, the electronic digital computer at the University of Illinois it took precisely 15 minutes to obtain the principal axes, a modified eigenvector solution maximising common variance components, and thereby characterising the principal relationships between wave-forms from a number of different scalp locations. Furthermore, individual vector scores have been calculated by matrix multiplying each person's separate measures by the inverse matrices of the principal axes components. Thereby it is possible to classify every person in relation to the population measured by his vector score on each axis, while a profile of each person's standard scores reflects focal variations between different parts of the head whence the wave samples came.

Robert Cohn (Bethesda, Md.):

I think that the cycloscope method that we used in 1941, with Dr. Douglass in Arizona, should have been considered in this presentation. Our results were extraordinarily similar to those which Dr. Brazier has presented today.

Frederic A. Gibbs (Chicago, Ill.):

Perhaps some of you will be interested in a simple photographic method of converting a strip of line-recording into a shadowgram. A negative is made of the line-recording and this is printed by projection on a high contrast film. While the positive is being exposed, instead of being held still, it is moved at a constant speed in a direction perpendicular to the long axis of the line-recording thus the line is "smeared out" across the lower half of the positive. The principle of the process is this — a moving dot registers on film as a line and a moving line registers as an area. I described the procedure in detail in *Science,* **1943,** *97*: 145-146.

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