A FOURIER TRANSFORM OF THE ELECTROENCEPHALOGRAM*

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(Received for publication, July 29, 1938)

THE electroencephalogram as usually recorded shows a confusion of wave forms and a mixture of frequencies which are impossible of accurate visual analysis. With experience one can learn to detect certain gross features which have significant clinical and physiological correlates, but in this there is more art than science. Certain crude indices which have been devised as a basis for comparison are open to theoretical criticism. They are not arrived at objectively, and do not afford a consistent expression for the data. The electroencephalogram, which is an amplitude *vs.* time function, can be expressed as a continuous plot of amplitude *vs.* frequency; that is, as a spectrum. The mathematical tool for making such a transposition is the Fourier Transform. The validity of expressing data of the type found in the electroencephalogram in terms of its Fourier Transform is generally recognized.[1,2] The only question that can be reasonably argued is whether such an expression is advantageous. We believe that it is, and have applied the Fourier Transform to a large number of electroencephalograms. The theoretical and practical advantages of this expression will be set forth below.

Not the least of its advantages is the simplicity with which it can be obtained by the mechanical-electrical integrator which one of us (A.M.G.) has designed. The technique is as follows: A representative oscillogram is taken as a shadowgraph on 35 mm. film, and later made into a continuous function by splicing the film to form an endless belt. The belt is revolved between a transverse slit of light and a photo-electric cell which reproduces the original electroencephalogram (Fig. 1). The resulting signal is passed through an extremely sharp variable electric wave filter. The speed of the belt and the speed of the frequency scanning mechanism is so arranged that the electroencephalogram to be analyzed can be treated as a repetitive function in this system. After being rectified the output of the filter is connected to a galvanometer which automatically records the amplitude of each differential frequency component on sensitized coördinate paper.

No objective method of analyzing the intricate wave forms of the electroencephalogram has previously been devised. The advantage of such a method in practice is that it is independent of the several intricate and arbitrary terminologies which have been devised for compiling results of studies on the electrical activity of the brain. It affords a relatively complete yet comprehensive expression for the data in terms of itself alone. It provides a common, rigorous, and mathematical expression for all types of record. Furthermore it ends the tedious work of measuring frequency by hand, and of estimating for

* This research has been aided by a grant from the Rockefeller Foundation.

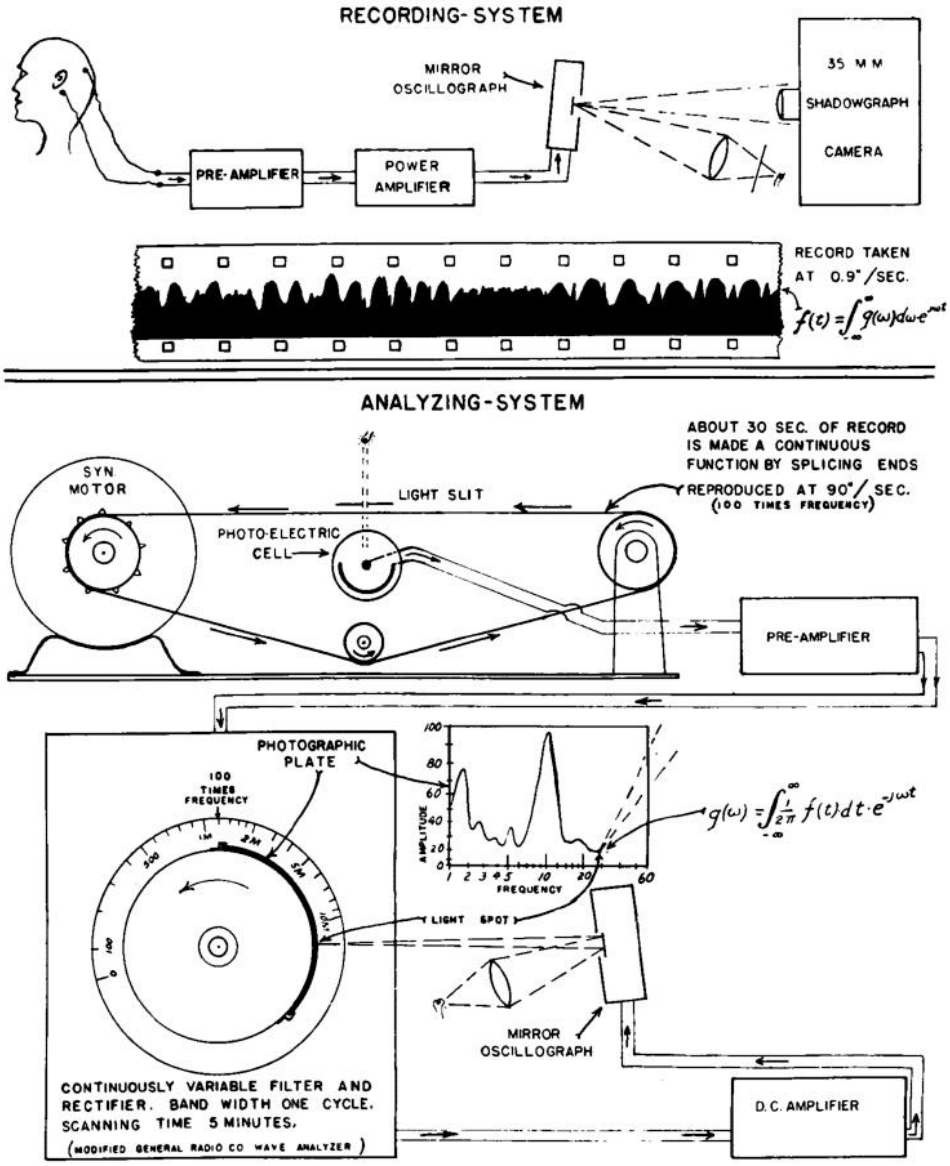

FIG. 1

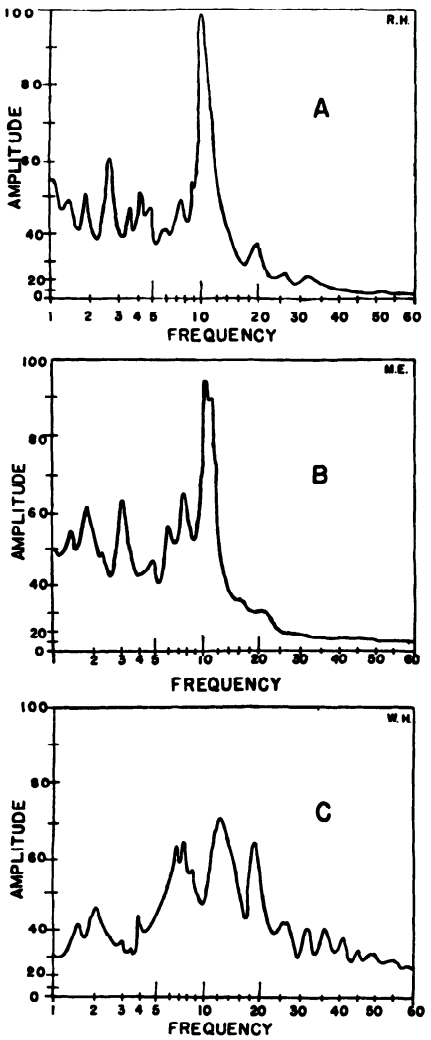

FIG. 2
3 NORMALS

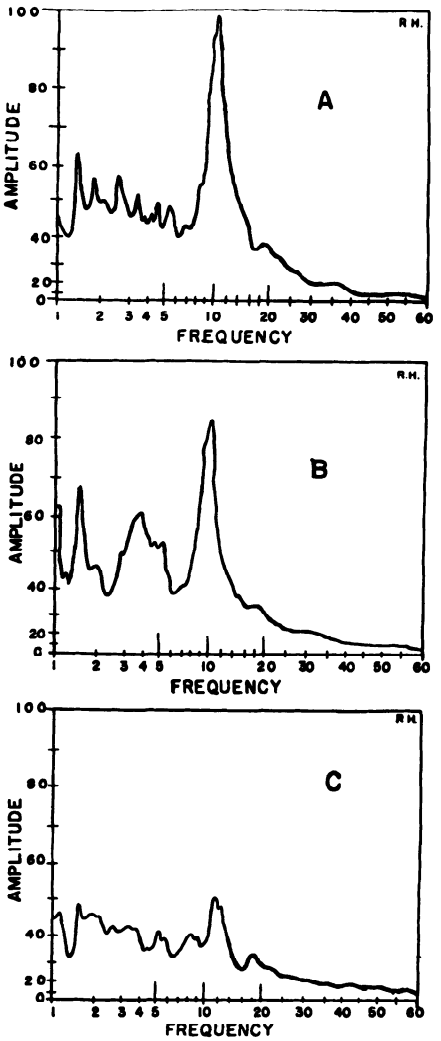

FIG. 3
A- NORMAL, EYES CLOSED
B- EYES OPEN, INACTIVE
C- EYES OPEN, READING

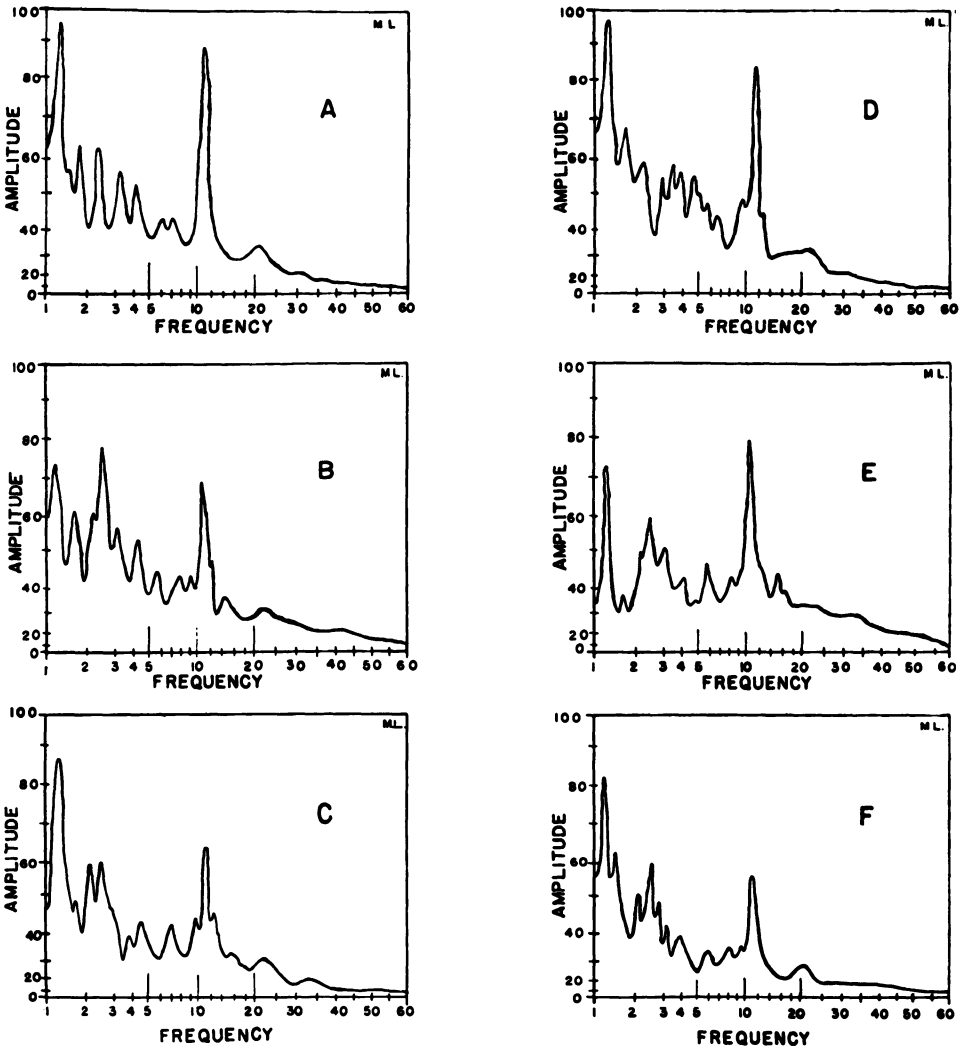

FIG. 4

ANALYSES OF RECORDS OF A NORMAL TAKEN AT 10 MINUTE INTERVALS

each component the percentage of time present, both of which procedures are as exhausting as they are inadequate and inaccurate.

The Fourier Transform is not proposed as a substitute for the customary oscillographic recording of the electroencephalogram, but rather as a supplement and a compact expression for such a record. The unanalyzed record is still indispensable for detecting short bursts of particular wave forms, phase relations, and "build-ups," all of which have been shown to be significant. These tend to be lost in the analyzed record. Nevertheless, the time element can be supplied in the form of consecutive analyses made at separate or continuous intervals of time.

Analyses have thus far been made of more than 300 records. These include a control group of 111 normals, 104 schizophrenics, and 84 epileptics. In many of the subjects observations were repeated at different intervals of time. In all cases records were taken from frontal, occipital, parietal and temporal lobes. Comparisons and data for these cases is being worked up and will be published in the near future. Analyses of the normal electroencephalograms made with leads on the left occipital area and on the ear reveal that energy is scattered over all frequencies from below 1 to approximately 60 cycles per sec., a range in which we are particularly interested. But more energy is found at cer-

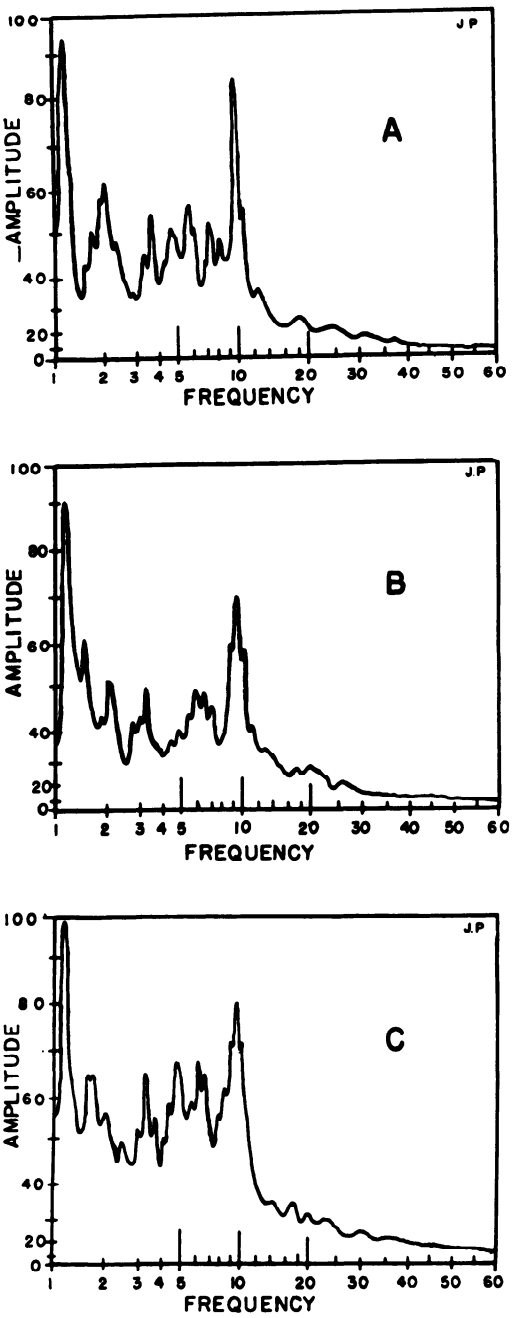

FIG. 5

ANALYSES OF A NORMAL'S RECORDS AT TWO DAY INTERVALS

tain group frequencies than at others. The most constant peaks are to be found in 1–12 and 18–22 cycles per sec. bands. Fourier Transforms from various normal records are shown in Fig. 2. Inspection of such continuous spectrums should convince one of the inadvisability of referring to certain potentials as alpha, beta, delta waves, etc.

Fig. 3 shows the changes in the analyzed electroencephalogram of a normal subject sitting at rest (A) produced by opening the eyes (B) and by reading (C). Inspection of these analyses will reveal data which are entirely hidden in the unanalyzed record, for example, the exact position of the 20 cycles per sec. peak. Such data may well be as important as observations which can be made on the unanalyzed record.

Transforms of electroencephalograms taken at ten-minute intervals during an hour (Fig. 4) and at two-day intervals (Fig. 5) indicate that although the electrical activity of the cortex may remain fairly constant, it does change. To determine the exact range through which it changes and the significance of these changes is more important than its "constancy." The center of area of the spectrum with respect to the frequency axis gives a numerical value which indicates how the energy of the spectrum changes from one group of frequencies to another from time to time and with administration of drugs, oxygen, etc. This figure as applied to several series of transforms appears to be useful. The true center of area which includes amplitude may also prove useful.

Summary

After having made transforms of 300 electroencephalograms, we are convinced that the system not only expresses data in a manner more useful and concise than is possible by present methods, but that in many cases it indicates important changes in the electroencephalogram which would otherwise remain hidden.

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