Henry Ford Hospital Medical Journal

Volume 19 | Number 4 Article 5

12-1971

The Symmetry-Decision Method of EEG Analysis

Richard M. Lee

Henry Ford Hosp. Med. Journal
Vol. 19, No. 4, 1971

The Symmetry-Decision Method of EEG Analysis

Richard M. Lee, Ph.D.*

An improved version of a previously presented computer analysis for EEG is described. The basic process used in the analysis is the classification of waves according to duration (frequency) and amplitude. The unique aspect of the improved system is the distinction between "simple" waves and "composite" waves, which are slow waves with superimposed higher frequencies. The computer program makes this "decision" on the basis of wave symmetry.

In 1967 I described a computer analysis of the electroencephalogram (EEG) which was based upon the identification of "wave" patterns.[1] The method was designed to simulate, with far greater speed and precision, the classification of EEG which is performed by an electroencephalographer. This paper describes a modification of that method, which provides both theoretical and practical improvements.

In the previous analysis, the EEG signal was analyzed by categorizing individual waves according to amplitude and duration. We considered "digitized" signal, that is, a series of integers (recorded on magnetic tape) which are proportional to the value of the voltage sampled at regular intervals, usually 100 to 300 samples per second. The first step in the analysis is the identification of maxima (peaks) and minima (valleys) in the digitized signal. Maxima are defined by a series of three points, the middle of which is greater than the other two. For minima, the middle point is less than the other two. The basic unit for the analysis is the "peak wave" which consists of all the points between two successive minima. After the peak waves are identified, they may be categorized according to wave length and amplitude.

One additional, key factor must be considered in any pattern analysis of EEG: the simultaneous occurrence of waves of different frequency. It is in the treatment of this factor that the previous and present methods differ. In the previous method, we used a digital "smoothing" process (analogous to electronic low-pass filtering) for the successive elimination of high frequency waves.

The digital smoothing procedure was performed as follows: In the first stage,

---

*Department of Neurological and Behavioral Sciences, Edsel B. Ford Institute for Medical Research; and Biomedical Data Processing Section, Henry Ford Hospital.

The computer time for this project was supported by a General Research Support Grant No. 5-SO1-RR05490-09 from the National Institutes of Health to Henry Ford Hospital.

all waves were identified and those with a frequency (defined as the reciprocal of wave-length) greater than 50 Hz were replaced by digits of constant value. Peak waves were then identified and classified by amplitude and duration. This process was repeated for frequencies of 25, 15 and 8 Hz so that four sets of data were obtained. Although this method provided a very comprehensive description of the signal, it had three disadvantages: (1) the time consuming process of making four separate analyses, (2) the difficulty in considering so much data, and (3) uncertainties about the relationships between each set of data. In the present method, we have eliminated these disadvantages by devising a "one-pass" system, which provides a more condensed set of data.

Symmetry-Decision Method

Figure 1 illustrates the definitions of the various wave properties. Part A shows a segment of EEG which is broken into half waves. Half waves 1L and 1R form peak wave 1, waves 2L and 2R form peak wave 2, and so on. The amplitude of a peak wave is the average of the magnitude of its left and right half waves. The term *frequency* as it is used in this analysis is defined as follows: A wave is said to belong to a certain frequency category if the reciprocal of its duration ($W_{2L} + W_{2R}$ in Part A) falls within the limits of that category. We use the term frequency, as opposed to wave-length, since electroencephalographers express their findings in this way. To illustrate, the amplitude of wave 2 (Part A) is $(M_{2L} + M_{2R})/2$ and the value of $1/(W_{2L} + W_{2R})$ would determine its frequency category.

Another property that is useful to define is *symmetry*. This is the ratio of the left magnitude component to the right (M_{1L} to M_{1R} for wave 1). Figure 1B illustrates waves of different symmetry.

In EEG signal, waves of different frequency may be present simultaneously—fast waves are superimposed on slow waves. Figure 1C illustrates this property. Waves 1 and 5 are simple waves, but waves 2, 3, and 4 may be grouped together and considered a "composite" wave. The interpretation of composite and simple waves is, of course, arbitrary. We have chosen the following definitions because they have proven useful and are consistent with our subjective interpretations. A composite wave is a group of peak waves, the first of which has a symmetry greater than 2 (see Fig 1B), the group of waves having an overall pattern similar to a simple wave (exact definitions are given below). Wave 2, Figure 1C illustrates the asymmetrical peak wave which serves to define the beginning of the composite wave, composed of waves 2, 3 and 4 in Figure 1C.

The symmetry-decision method may be better understood by considering the sequence of procedures which is used in an actual analysis. The signal is first analyzed into components (as illustrated by Fig 1A). The symmetry of the first peak wave is examined. If it is relatively symmetrical, between 2 and 0.5 (refer to Fig 1B), it is classified as a *simple* wave, its amplitude and frequency category are computed, and we go on to the next peak wave. If the symmetry is more than 2, the wave is considered the first component of a composite wave. The next wave (which

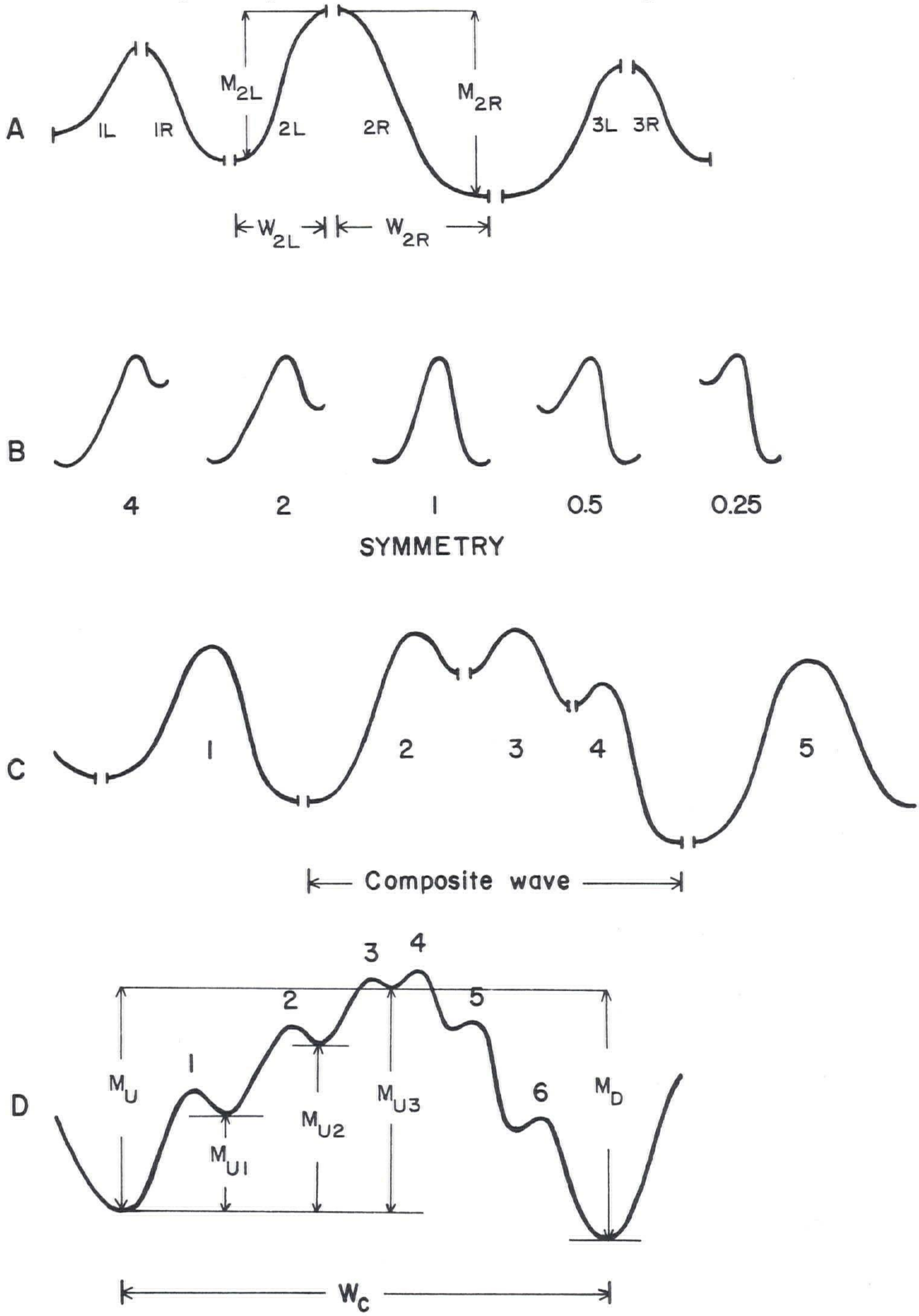

Figure 1
Definitions of wave properties. See text for explanation.

forms the second component of the composite wave) is then examined and if the *pair* of waves meet certain symmetry requirements the composite wave is considered complete, its amplitude and duration are computed and we go on to the next wave. If the symmetry requirements are not met, each successive wave is added to the original pair, and when the requirements are satisfied, the composite wave is said to be complete.

Some further definitions are needed before the details of the method can be explained. Figure 1D illustrates the computation of M_U and M_D which are the analogs of M_L and M_R for simple waves. When a composite wave is being formed, as each new peak wave is added, a new value of M_U is computed by adding on (M_L—M_R). When the peak is reached (between waves 3 and 4 in the figure) then M_D is successively computed by adding (M_R—M_L). Note that M_D grows in *positive* magnitude as the composite wave increases in the *downward* direction. The amplitude of the composite wave is $(M_U + M_D)/2$ and the duration is W_C.

The rules used by the analysis were developed by a trial-and-error procedure working with actual EEG signal. The goal was to obtain a computer program which could discriminate simple and composite waves in a way which approximates the subjective rules used by the electroencephalographer.

Two rules apply for *simple waves:* (1) the wave symmetry must be less than 2, and (2) the next wave must have a symmetry greater than or equal to 0.5.

The rules for defining *composite waves* are as follows: The first wave must have a symmetry greater than 2. Each successive wave is added to the rising part of the composite providing its symmetry is greater than 1.0. When a wave has a symmetry less than 1.0, we begin to compute M_D. When $M_D \geqq M_U/2$, the rising part of the wave is considered complete and M_U is fixed. However, we allow for "small" downward excursions within the overall rising part of the wave as long as $M_D < M_U/2$. Another consideration is that there may be a shift in the absolute value of the EEG signal. If we have advanced 12 waves with $M_D < M_U/2$ we "back-up" 10 waves and go on with the wave analysis.

There are three alternative ways in which to complete the composite wave. We have found the last wave if: (1) the next wave has a symmetry greater than one, (2) the next wave has a symmetry greater than 0.5 and M_L (its left half wave height) $\geqq M_U/2$, or (3) the next wave has a symmetry greater than or equal to 0.5 and the previous $M_D > M_U$.

Figure 2 is a flow chart which explains the details of the symmetry-decision process. The analysis begins at 1. START and proceed to 2, where the first peak wave is examined. If the symmetry of that peak wave is less than 2 (refer to Fig 1B) proceed to 3, if greater than or equal to 2 proceed to 4, etc.

Illustrations of some of the more important features of the analysis are shown in Figure 3 (numbers refer to statements in Fig 2). Statements 3 and 4 provide the basic distinction between simple and composite waves. Statement 3 leads to the classification of a simple wave unless the next wave has a symmetry less than 0.5 (statement 7). If

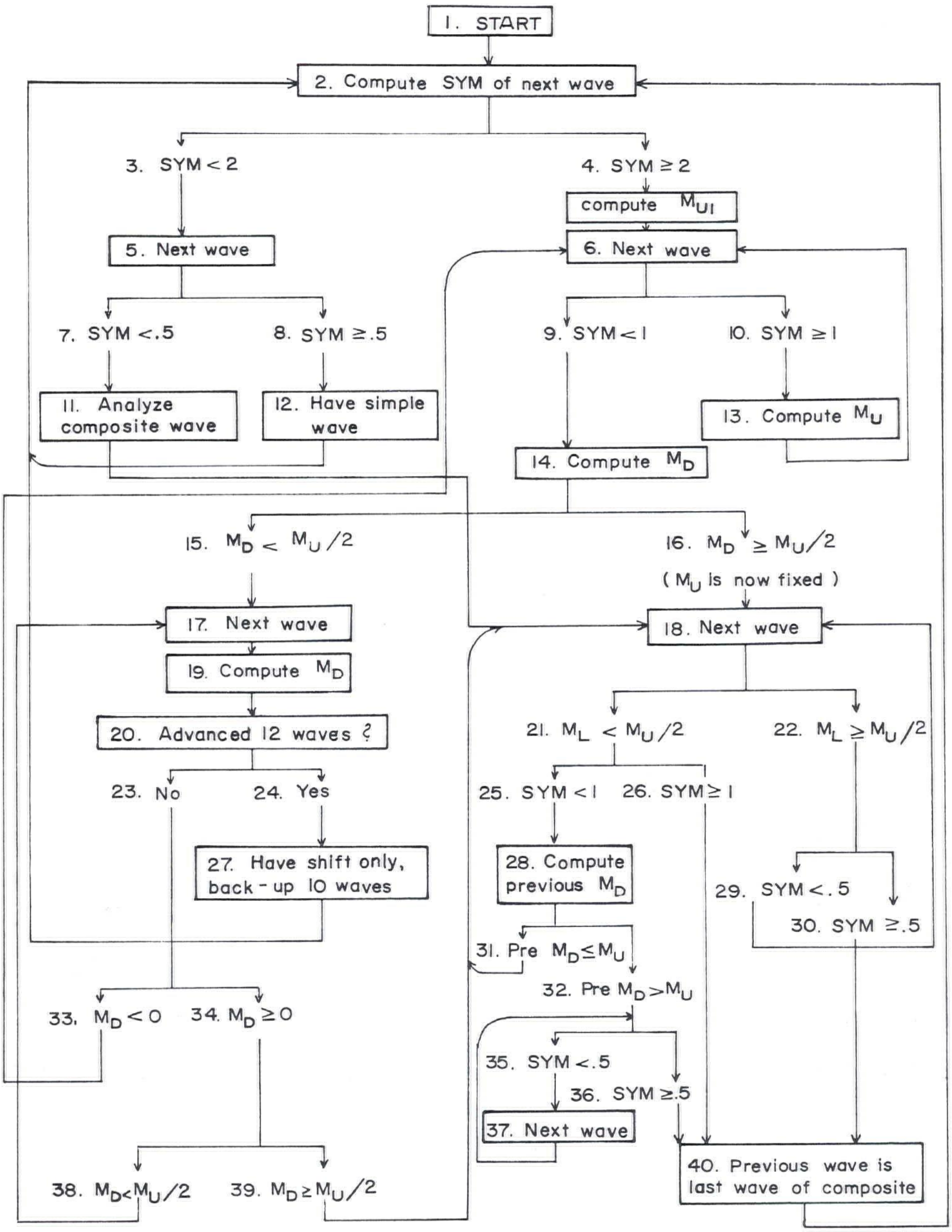

Figure 2

Flow chart of symmetry-decision method. See text for explanation.

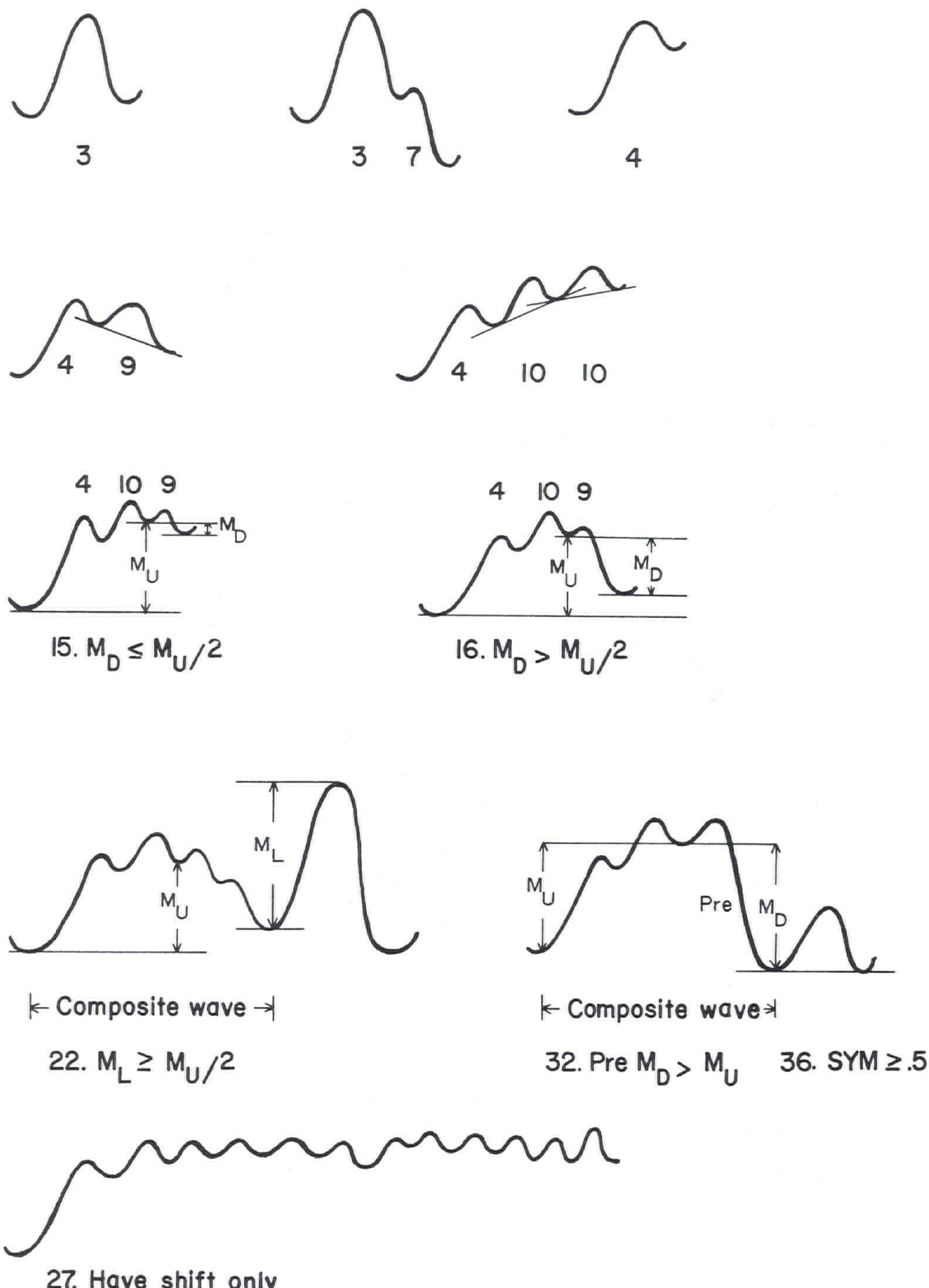

Figure 3

Illustrations of various aspects of the symmetry-decision method. See text for explanation.

statement 7 is true, we proceed to statement 18 which is in the composite wave procedure. Returning to sequence beginning with statement 4, the next wave may begin the descent (statement 9) or continue the ascent (two loops through statement 10 are illustrated).

The distinction between statements 15 and 16 is very important to the analysis of composite waves. When the descending portion of the partial composite wave is greater than one-half the ascending portion (approaching a symmetrical pattern), M_U can no longer be changed and further rises mark the completion of the composite wave.

When statement 16 is true, the usual case is statement 21 (statement 22 is an unusual occurrence and is illustrated in Fig 3). The composite wave is usually completed either by statement 26 (any wave of rising form) or if the previous M_D is greater than M_U by statement 36 (any wave with symmetry greater than 0.5).

When statement 16 is not true, after proceeding to 12 waves, we assume that a shift in average potential has occurred (rather than a composite wave), and go back to statement 2.

Discussion and Summary

In the symmetry-decision method, EEG signal is analyzed into simple and composite waves, and these waves are classified according to amplitude and frequency categories. A simple wave is a peak wave which appears symmetrical, like a sine wave. A composite wave is a long-duration (slow) wave with a superimposed higher frequency signal.

In the previous paper[1] I discussed some of the advantages of this approach over other types of analyses (see reviews by Walter and Brazier[2] and Dubes[3] for descriptions of other techniques). The main argument is that this procedure provides a more complete description of the EEG in terms which are easily interpreted. The advantage of this analysis over the previous one is that it requires only one pass through the signal instead of four successive passes after digital filtering. It also has an advantage in that each interval of EEG is treated in only one way. In the previous analysis, a particular wave could be represented in more than one set of data.

Dubes[3] has provided a recent review of EEG analyses and has categorized them according to four levels: (1) the traditional reader of an EEG by an electroencephalographer, (2) a human analysis after an initial data reduction, (3) human analysis after "primitive feature selection" and (4) a complete computer analysis in which decisions are made by the program on the basis of primitive feature selection (level 3). My program is classified at level three, primitive feature selection. The fourth level is still in an experimental state and it is an attempt to program a computer to perform some of the interpretive and interactive processes which the "human analyzer" usually employs.

Two approaches may be used in presenting results obtained with the symmetry-decision method. One is to analyze a particular interval of EEG, say 20 sec, in great detail. Bar graphs may be used to represent the number of simple and composite waves classified in each amplitude and frequency category. The other approach is to choose certain categories and to follow changes in these for long periods of time. Some categories found useful for this method are the following: the percentage of time in which the signal was composed of a particular frequency category such as 8 to 12 Hz (alpha waves), the percentage of all waves in higher amplitude categories, and the mean frequency (weighted by time) of the signal.

The method has been successfully applied to EEG recorded from divers exposed to a simulated (by means of high pressure) dive of 1000 feet.[4] Using this method, we were able to show that the number of high amplitude waves decreased and the number of waves in the 6 to 8 Hz frequency category increased during the compression phase of the experiment. We were also able to make a complete analysis of a seizure discharge recorded during the experiment.

Acknowledgement

I thank Ingeborg Higgins for her excellent art work.

REFERENCES

1. Lee, R. M.: A wave pattern analysis for EEG signal based upon a successive digital smoothing process. *Henry Ford Hospital Med Bull* 15:33-47, Mar 1967.

2. Walter, D. O. and Brazier, M. A.: Advances in EEG analysis. *Electroenceph Clin Neurophysiol* Suppl. 27, 1968.

3. Dubes, R. C.: Pattern recognition with clinical electroencephalograms. Interim Report No. 13 AFOSR-1023-67B, Division of Engineering Research, Michigan State University, East Lansing, Michigan, (1970).

4. Proctor, L. D., et al: Electroencephalographic changes during saturation excursion dives to a simulated seawater depth of 1000 feet. Paper read at International Physiologic Congress, Marseille, July 24, 1971.