sults are consistent with the position that change in the adaptation level of the reticular formation, either by increase or decrease of sensory stimulation, is capable of effecting arousal in a sleeping animal.

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References and Notes

1. S. Sharpless and H. H. Jasper, *Brain* **79**, 655 (1956).
2. D. B. Lindsley, in *Neurophysiology*, Sec. 1 of *Handbook of Physiology*, J. Field, Ed. (American Physiological Soc., Washington, D.C., 1960), vol. 3, pp. 1553–1594.
3. Grayson-Stadler.
4. Grass P-4.
5. Measured by a General Radio sound level meter.
6. Trials were not given during episodes of low-voltage sleep—that is, "paradoxical sleep." On these infrequent occasions, intervals between trials were as long as 10 minutes, while the experimenter delayed trial onset until a high-voltage pattern returned.
7. Stimulus decay was measured by means of an oscilloscope, a Shure No. 245 microphone being used as transducer.
8. D. B. Lindsley, in *Sensory Deprivation*, P. Solomon *et al.*, Eds. (Harvard Univ. Press, Cambridge, Mass., 1961); and in *Nebraska Symposium on Motivation*, M. R. Jones, Ed. (Univ. of Nebraska Press, Lincoln, 1957).
9. Supported by ONR contract Nonr-233 (32). One of us (N.M.W.) is a National Institute of Mental Health postdoctoral fellow, No. 2-F2-MH-10,327.

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Electroencephalographic Data: Reduction by Wave-Width Analysis

Abstract. *While frequency analysis of the electroencephalogram is not unusual, relatively little examination has been performed in the time domain. Separation of the waves into the intervals of their duration above a baseline, irrespective of wave shape, has allowed a simple, numerical distinction to be made between the "eyes-open" and "eyes-closed" electroencephalogram.*

During investigations in our laboratory in which the electroencephalographic record was used to study and identify arousal of the cat from the sleeping state, visual examination was considered sufficient to identify the amount of synchronous activity (*1*). While this technique was entirely adequate for identification of well-defined (extreme) equilibrium states of sleep and arousal, for evaluation of the transitional periods, which were much more indefinite, some type of data reduction system was indicated. Two factors were considered important in the selection of such a system. First, since synchrony and asynchrony appeared to be of equal importance, equal weight should be given to waves of both large and small amplitude. Second, in the event short time periods were critical, analysis in the time domain would be more adaptable than frequency domain analysis.

For these reasons attention was given to reducing the electroencephalographic amplitude time-series with respect to the period (half wave length) between successive baseline crossings. The basic unit of period is similar to that suggested by Stein, Goodwin, and Garwin (*2*), Prast and Noell in 1949 (*3*), and Burch, Saltzberg, and associates (*4*). By this technique, rectangular waves of equal height are produced with duration determined by the time the input discriminator is exceeded and the point at which the amplitude drops below the discriminator value.

The actual electroencephalographic data are recorded on frequency-modulated tape with a bandwidth from 0 to 250 cy/sec. The analysis through a separate system is shown schematically in Fig. 1. The basic discriminator for conversion of the individual waves to shaped rectangular pulses is a modified, transistorized Schmitt discriminator. While this discriminator may be placed arbitrarily at any higher setting, the minimal setting practical at the present time is equivalent to 5-μv input. Any lower setting of the discriminator (that is, closer approach to the theoretical baseline) is at this time prohibited by the inherent noise in the system. Since most of the electroencephalographic recording falls within a dynamic range of 25, this circuit must exhibit no overload characteristics within such a range.

The duration of the shaped rectangular pulse is measured by gating a clock-pulse generator by the leading and trailing edges of the shaped pulse. After differentiation of the rectangular pulse the leading edge initiates the gating pulse for the clock generator. The clock generator continues to run until the trailing edge terminates the gate. The number of clock pulses generated is then proportional to the frequency of the clock and duration of the gating pulse. In the example shown, a frequency of 1000 pulses per second is utilized; thus for a 14-msec wave, 14 pulses are produced. In practice a 100 kilocycle crystal-controlled oscillator is used as the master clock with a variable scaler reducing the effective frequency to the time resolution desired. Channeling of the burst of clock pulses into storage bins related to the number of counts in the burst has been accomplished by the address scaler and storage units of a Victoreen 120 pulse-height analyzer. In this unit, two decade Burroughs switching tubes are utilized to form an address scaler with channels of 1 to 100. Twenty storage channels are available to tabulate any 20 of these channels at one time. The present techniques have tabulated pulses of 1-msec duration. This resolution, however, appears to be in excess of what is needed, and in the following histograms of pulse-width distributions bins of 4-msec increments have been recorded.

In a first investigation with this system, histograms of pulse-width distribution were obtained from frontal-occipital and parietal-occipital leads of subjects with eyes alternately open and closed. The subjects were young adult male and female volunteers with no known psychiatric or neurological history and were selected without special criteria regarding their electroencephalograms.

Repetitive trials showed the predominant alpha-waves present during the

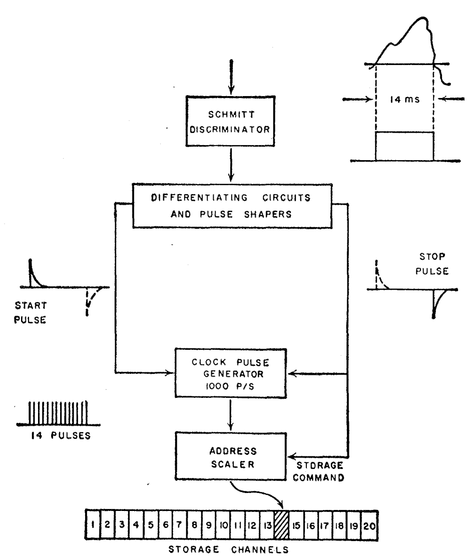

Fig. 1. Schema of electronic technique of pulse-width analysis showing a single theoretical electroencephalographic wave of 14-msec duration with subsequent shaping and relations necessary for analysis and storage.

"eyes closed" state as contrasted with the activated record during the "eyes open" period. These data were analyzed at 4-msec intervals and then grouped in 16-msec increments for plotting. They represent averages obtained from five 60-second samples of eyes open and closed recorded from 13 subjects. Since the 60-second sampling time was not long enough to contain large numbers of each increment, the problem of random sampling predicted a reasonably large variation between samples. However, in the range of moderate widths especially, the variance between trials is small. The results plotted as histograms are shown in Fig. 2 for the frontal-occipital recordings.

With the data from two recording sites, a four-way factorial analysis of variance (F) was carried out. The results show that the wave-width distributions are significantly different for the two states [F (4, 52) = 109.90, $p < .001$]. The analysis indicated that the wave-width distributions for the two channels also differed although a visual analysis of the ink-written recordings revealed no systematic differences [F (4, 52) = 4.04, $p < .01$]. The data recorded from occipital-parietal in contrast with frontal-occipital recordings tended to yield distributions with a greater number of short duration waves and a fewer number of waves of moderate duration (37 to 69 msec). Although not of special interest in the current study, the sensitivity of the techniques is demonstrated by the significance of the third order interaction [F (4, 52) = 3.10, $p < .05$] which indicates that the differences between wave widths for the two states of consciousness themselves differed for the two recording areas.

Several factors are apparent in the pulse-width histogram. First, as shown in Fig. 2, the total number of pulses analyzed is greatly in excess of those visually examined in the ink-written record. In the ink-written record, little opportunity is given to identifying waves of period width less than 10 msec (50 cycle). As seen in the activated record, however, waves less than this width actually comprise 85 percent of the total distribution. Second, the upper end of the spectrum appears to be as indicative of the two physiologic states as the lower spectrum. There is as consistent a change between the "eyes open" and "eyes closed" distribution even in the 4- to 16-msec wave widths as well as in the lower frequency region.

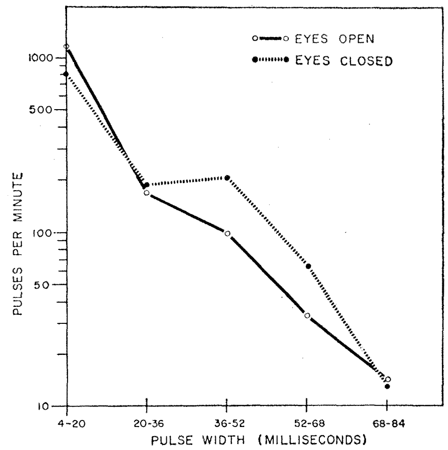

Fig. 2. Pulse-width histogram of the two contrasted states on frontal-occipital recording. The plotted values represent the averages of 14 subjects analyzed in 16-msec intervals (4 to 84 msec). Each subject has been recorded with five trials "eyes open" and five trials "eyes closed," 60-second duration per trial.

The distribution of these data emphasizes the continuous nature of the spectrum and indicates that the appearance of the alpha-waves is not seen as a specific frequency but occupies a broad and continuous segment of the spectrum. This is in contrast to the alpha-spectrum systems usually derived from Fourier analysis or other examinations in the frequency domain. Two factors are responsible for this difference. The Fourier coefficients are dependent upon the amplitude of the wave; thus the large amplitude alpha-waves dominate the appearance of the Fourier transform even though the number of such waves may be small. Secondly, the coefficients of any analysis in the frequency domain are influenced not only by the width of the waves but also by the repetition frequency.

The continuous nature of the data is also noted by the approximate fit into an exponentially decreasing distribution. It may also be observed that the appearance of the broad alpha-synchrony in the "eyes-closed" recording suggests two exponential components as an approximation by an initial curve fit. While the best fit of the pulse-width histogram into a continuous function has not yet been realized, the description of the histogram in actual number of waves has been readily adaptable for statistical analysis. In the above recording, comparisons have been made not only of the distribution of width in the "eyes open" and "eyes closed" states, but also comparing the placement of electrodes, repetition of trials and variation between subjects.

At present all the distributions shown have been recorded at the same discriminator value. By either raising the discriminator setting or reducing the gain of the playback amplifier, only the larger waves may be selected for analysis. We are uncertain concerning the number of levels that may be required to adequately describe this data. The division of Burch and Saltzberg of the periods into major and minor modes, however, suggests that perhaps as few as two levels may be adequate for most purposes.

In summary we might say that this system of analysis appears to offer several advantages. (i) The full spectrum of electroencephalographic activity is recorded with equal emphasis given to all durations independent of amplitude. (ii) The resolution in time or interval between crossing is readily adaptable to as long or as brief duration as may be required. At present an upper limit of 100 μsec may be realized. (iii) Brief epochs may be analyzed with no reflection of later events into the early section of analysis. (iv) The device is relatively simple electronically and the analysis time is sufficiently brief that it may be used as an on-line device during the conduction of an actual experiment if desired. (v) A direct numerical recording is made of all distributions which makes the application of statistical analysis and mathematical transformation of the data readily available.

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References and Notes

1. H. Gluck and V. Rowland, *Electroencepalog. Clin. Neurophysiol.* **11**, 485 (1959).
2. S. N. Stein, C. W. Goodwin, J. S. Garvin, *Trans. Am. Neurol. Assoc.* **74**, 197 (1949).
3. J. W. Prast and W. K. Noell, *U.S. Air Force School Aviation Med. Rept. 21–02–050* (1949).
4. N. R. Burch, *Electroencephalog. Clin. Neurophysiol.* **11**, 827 (1959); B. Saltzberg, N. R. Burch, M. A. McLennan, E. G. Correll, *IRE (Inst. Radio Eng.) Trans. Med. Electron.* **8**, 24 (1957).

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