Sleep, 4(2):193–206

Spectral Analysis vs. Period-Amplitude Analysis of Narrowband EEG Activity: A Comparison Based on the Sleep Delta-Frequency Band

*,†Periklis Y. Ktonas and *Atul P. Gosalia

**Electrical Engineering Department, University of Houston, Houston; and †Psychiatry Department, Baylor College of Medicine, Texas Medical Center, Houston, Texas*

Summary: This paper presents a comparison of spectral analysis with period-amplitude analysis when applied to the quantification of narrowband electroencephalographic (EEG) activity. In particular, it examines their respective usefulness in quantifying on the average the electrographic content within the delta-frequency band of EEG epochs during human stage 4 sleep. It is shown that while the power spectrum efficiently quantifies the overall power trends in the EEG data, period-amplitude analysis seems to offer more resolution than the power spectrum in detecting electrographic details in amplitude and incidence within relatively narrow frequency bands. Examples are given of the sensitivity of spectral analysis to both wave amplitude and incidence, and of the fact that—due to the inherent averaging process in the power spectrum generation—spectral analysis cannot differentiate between low-amplitude, high-incidence EEG activity and high-amplitude, low-incidence EEG activity, in contradistinction to period-amplitude analysis. It is also shown that although two EEG epochs may exhibit similar power spectrum plots, their corresponding period-amplitude plots may not be similar. It is emphasized that discrepancies may exist when comparing spectral to period-amplitude analysis due to differences in the definition of "frequency" in the two techniques. **Key Words:** Electroencephalogram—Power spectrum—Period—Amplitude—Delta waves.

In the last two decades much effort has been directed toward the general problem of automating electroencephalogram (EEG) analysis. Various techniques have been proposed for the automatic detection of particular waveforms, quantification of background rhythms, sleep EEG staging, and automatic EEG report generation (Kellaway and Petersén, 1973, 1976; Dolce and Künkel, 1975; Gevins et al., 1975; Rémond, 1977; Smith, 1978; Barlow, 1979). With the advent of fast and relatively

---

Accepted for publication February 1981.

Address correspondence and reprint requests to Dr. Ktonas at Electrical Engineering Department, University of Houston Central Campus, Houston, Texas 77004.

inexpensive general-purpose minicomputers equipped with efficient fast Fourier transform (FFT) algorithms, spectral analysis has become a popular technique for the analysis of EEG data in the frequency domain (Dumermuth et al., 1975). On the other hand, time-domain EEG analysis techniques, especially period-amplitude analysis (Burch et al., 1964; Stigsby et al., 1973; Sharp et al., 1975; Barr et al., 1978), are also popular, primarily due to the fact that results derived from these techniques may agree more closely with visual EEG analysis than results obtained via spectral techniques (Schenk, 1976).

Spectral analysis can provide an efficient quantification of overall broadband rhythms present in an EEG epoch. Thus, EEG data presentation in terms of compressed spectral arrays (CSA) has proven useful in long periods of recording (Bickford, 1977). However, being an averaging process over a given time window of data, spectral analysis does not characterize EEG details well, in particular transients such as sleep σ-spindles or K-complexes. Period-amplitude analysis, on the other hand, since it treats the EEG as a superposition of waves with particular individual periods and amplitudes, can be used for detailed EEG quantification by measuring the EEG duration and peak amplitude between successive zero-crosses. Therefore, it can be used to measure time-domain characteristics within a narrow EEG frequency band, and in some ways of operating it has proven useful for the detection of EEG transients such as K-complexes and sleep σ-spindles (Bremer et al., 1970; Smith et al., 1975). However, when period-amplitude analysis is used by averaging individual wave periods and peak amplitudes over a given time window of narrowband EEG data, one might expect both spectral and period-amplitude analyses to give similar results.

This paper presents a comparison of spectral analysis and period-amplitude analysis as they are used to quantify on the average the electrographic morphology of epochs of narrowband EEG data, in particular activity within the delta-frequency band of human sleep EEG.

METHODS

Data Acquisition

The recording of the sleep EEG (male young adult) was made with a Grass-78 polygraph. The low-frequency time constant of the polygraph amplifiers was set at 1 sec, which corresponds to a lower frequency cutoff with 50% attenuation at 1 Hz. Three pairs of EEG electrodes were placed in accordance with the 10-20 International System as follows: F_1/F_7, C_3/A_2, O_3/O_zP_z (Williams et al., 1974). In addition, two pairs of electro-oculogram (EOG) electrodes were utilized. All data channels were recorded on paper at a speed of 15 mm/sec and on magnetic tape using a Sangamo-3500 FM tape recorder at a speed of 15/16 ips. The raw (paper) EEG data were manually scored for sleep stages using the criteria of Williams et al. (1974).

Artifact-free periods of sleep stage 4 from the F_1/F_7 electrode derivation were played off-line from the Sangamo-3500 tape recorder, at a real-time speed, into the analog-to-digital (A/D) converter (12-bit resolution) of a TI-980A general-purpose digital minicomputer. The reproduced raw EEG signal was passed through a bandpass prefilter with a bandwidth of 0.1–9 Hz (12 dB/octave roll-offs) before it was fed into the A/D converter. Since we were interested in EEG activity of up to about 3 Hz (delta-activity band), and since most of the time this activity appears in aperiodic bursts, we utilized a wideband analog prefilter in order not to distort or attenuate such activity. The choice of the optimum bandwidth for the prefilter was based on previous work on rapid eye movement-related EOG waveform detection (Ktonas and Smith, 1978). The filtered EEG signal was sampled at 128 samples/sec, and the resulting digitized data were stored on disk for further processing. All subsequent data analysis was done on the TI-980A minicomputer. The digitized data were divided into 16-sec epochs, and each epoch was subjected to both period-amplitude and spectral analysis. Before the period-amplitude detection and the power spectrum computation, the mean value for the 16-sec EEG epoch under investigation was calculated and subtracted from the data.

Period-Amplitude Detection

The method consisted of finding the period and peak amplitude between two consecutive zero-crossings which define an EEG half-wave. The zero-crossings were detected by positive-to-negative and negative-to-positive transitions of the sampled EEG. The use of analog bandpass prefiltering and the low sampling rate minimized the chances of detecting zero-crosses due to high-frequency noise (Carrie, 1973). However, in order to prevent any residual small-amplitude, high-frequency noise from contributing to false zero-crossings, minimum amplitude and period criteria (threshold criteria) were used (Sharp et al., 1975). The period of the EEG half-wave was calculated by counting the number of samples between two consecutive zero-crossings and by multiplying this number by the inverse of the sampling frequency. The peak amplitude was calculated by finding the maximum-valued sample between those two zero-crossings. Both positive-going and negative-going half-waves were analyzed, and therefore, the absolute value of the peak amplitude between two zero-crossings was calculated.

Power Spectrum Computations

Power spectra were computed via FFT techniques (Bendat and Piersol, 1971). Before being transformed, the first and last 10% of the data were tapered with a cosine window to minimize leakage. Frequency-domain smoothing was performed to increase the statistical stability of the spectra. Nine contiguous frequency components of the raw power spectrum were averaged, resulting in a frequency resolution of about 0.56 Hz for the smoothed spectrum.

Data Presentation

The minimum and maximum spectral frequency components were arbitrarily set at 0 and 2.5 Hz, respectively. The range 0–2.5 Hz does not correspond to the delta band as used in sleep research (0.5–3.0 Hz), but it is very close to it, and since the objective of this work was not to perform a statistical analysis on the delta band proper, but to provide methodological insight, it was thought accept-

TABLE 1. *Frequency bands used for power spectrum and period-amplitude analysis*

Frequency band number[a]	Frequency bounds of averaged spectral components (Hz)	Final spectral frequency bounds (Hz)	Samples in half-waves (*n*)	Corresponding frequency bounds for period–amplitude analysis (Hz)
1	$0-{}^{4}/_{16}$ or 0–0.25	0–0.28	>227	0–0.28
2	${}^{5}/_{16}-{}^{13}/_{16}$ or 0.31–0.81	0.28–0.84	226–75	0.28–0.85
3	${}^{14}/_{16}-{}^{22}/_{16}$ or 0.87–1.37	0.84–1.40	74–45	0.86–1.42
4	${}^{23}/_{16}-{}^{31}/_{16}$ or 1.43–1.93	1.40–1.96	44–32	1.45–2.00
5	${}^{32}/_{16}-{}^{40}/_{16}$ or 2.00–2.50	1.96–2.53	31–25	2.06–2.56

[a] Smoothed spectrum and period-amplitude analysis plots.

able. The remaining components from the Fourier spectral analysis (up to 64 Hz) were discarded. Table 1 presents the final frequency bands obtained and the corresponding frequency ranges. As shown in this table, the first spectral frequency band (0–0.25 Hz) had five elementary spectral estimates included in it, while each of the remaining four bands included nine elementary spectral estimates. The final spectral frequency bounds were chosen for continuity purposes. Note that each final spectral frequency bound was derived from the corresponding frequency bound of averaged spectral components by augmenting the latter by one-half the elementary spectral band (about 0.03 Hz). The frequency band in which a particular half-wave belonged was computed as the inverse of twice its period. Care was taken to match as closely as possible the frequency bounds of those bands to the ones defined from spectral analysis. Table 1 shows that the frequency bounds of the five bands derived from period analysis are very close to those defined from spectral analysis (Final spectral frequency bounds, Table 1). The few discrepancies shown were unavoidable, since they were due to the choice of the elementary spectral band, the number of the contiguous spectral components which were averaged, and the sampling frequency.

For each 16-sec EEG epoch the percentage of half-waves (occurrences) in each frequency band and the average half-wave peak amplitude for that band were obtained and plotted as histograms. These histograms were compared visually to the power spectrum plot for the corresponding EEG epoch.

RESULTS

Figure 1 is an example of the data presentation for the comparison of period-amplitude analysis to spectral analysis: part (a) shows the 16-sec EEG epoch (analog prefiltered data) that was analyzed; part (b) shows the percentage of occurrence of the EEG half-waves in each of the five frequency bands of interest; part (c) shows the average of the half-wave peak amplitudes in each of the five frequency bands; and part (d) shows the power spectrum of the EEG epoch in (a).

In general, the power spectrum effectively quantified the overall presence of slow EEG activity (delta waves) in the epoch under investigation. However, there were cases of a pair of epochs exhibiting the same power content for the same frequency bands of the power spectrum, while showing different percentage of occurrence of EEG half-waves in those bands. Figure 2 presents an example of such a discrepancy: In both parts of the figure, the spectral power in the frequency bands 1–4 is almost the same; however, Fig. 2A shows less percentage of half-wave occurrences in the fourth band than does Fig. 2B, while the latter shows a greater percentage in the third band and less in the fifth band than Fig. 2A. Therefore, although two EEG epochs can be labeled "equivalent" for certain frequency bands, as far as their power spectra are concerned, detailed differences in their electrographic morphology seem to be detected through period analysis. This should not come as a surprise, since the concept of "frequency" in spectral analysis is different from that used in period analysis, and it may lead to the disagreement shown above (see Discussion).

In most cases, it was observed that the spectral plots did not resemble the

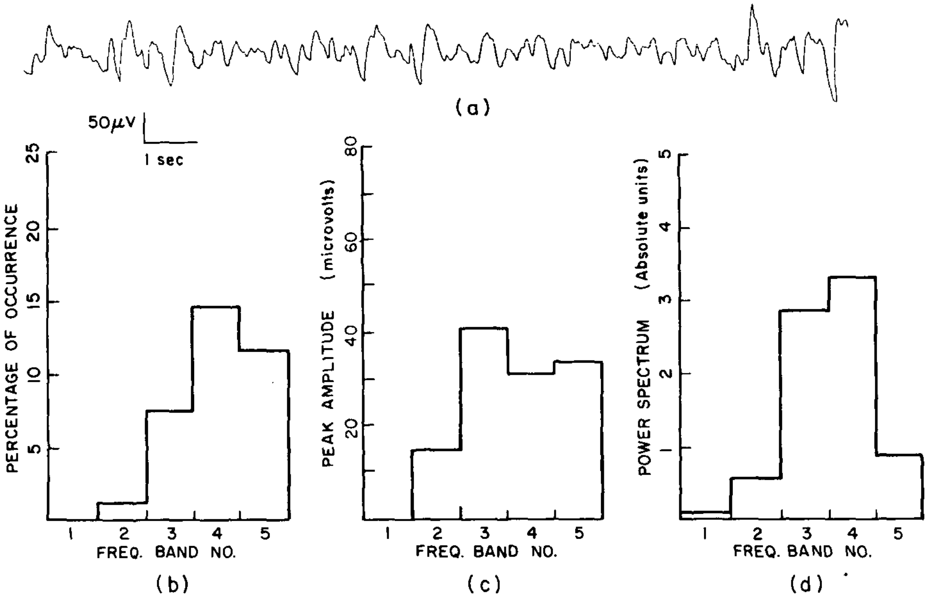

FIG. 1. (a) Analog prefiltered EEG data. (b) Percentage of occurrence of EEG half-waves vs. frequency. (c) Average peak amplitude of EEG half-waves vs. frequency. (d) Power spectrum of EEG epoch in (a). Observe the differences between the power spectrum and the percentage of occurrence plots.

corresponding percentage of occurrence plots. Usually, the occurrence plots showed a peak within the fourth frequency band (1.45–2.00 Hz), while the corresponding power spectrum plots showed a peak within the third frequency band (0.84–1.40 Hz). This discrepancy in the position of the "dominant" frequency within the delta band, which is seen in Fig. 2, can be explained by the already mentioned differences in the definition of frequency in the two methods of analysis. Another explanation, related to the above, is the fact that spectral analysis is amplitude-sensitive, while period analysis is not. Therefore, frequency components of high amplitude result in a larger contribution to the power spectrum than components of lower amplitude—which, nevertheless, show a contribution, proportional to their number, to the occurrence plot. This effect is clearly seen in Fig. 3: although the second frequency band shows a very low percentage of occurrence, the power spectrum plot exhibits a considerable amount of power in this band, since this band has the highest mean peak amplitude of all bands due to high-amplitude waves (underlined portion in Fig. 3a). Conversely, although the third and fifth frequency bands show almost the same percentage of occurrence, the power spectrum plot shows considerably less power in the fifth band because this band has about three-fourths the mean peak amplitude of the third band. The overall effect of the above may have resulted in the power spectrum plot showing a peak at the third frequency band, while the percentage of occurrence plot shows a peak at the fourth band.

Most of our data indicated that the power in a power spectrum plot is propor-

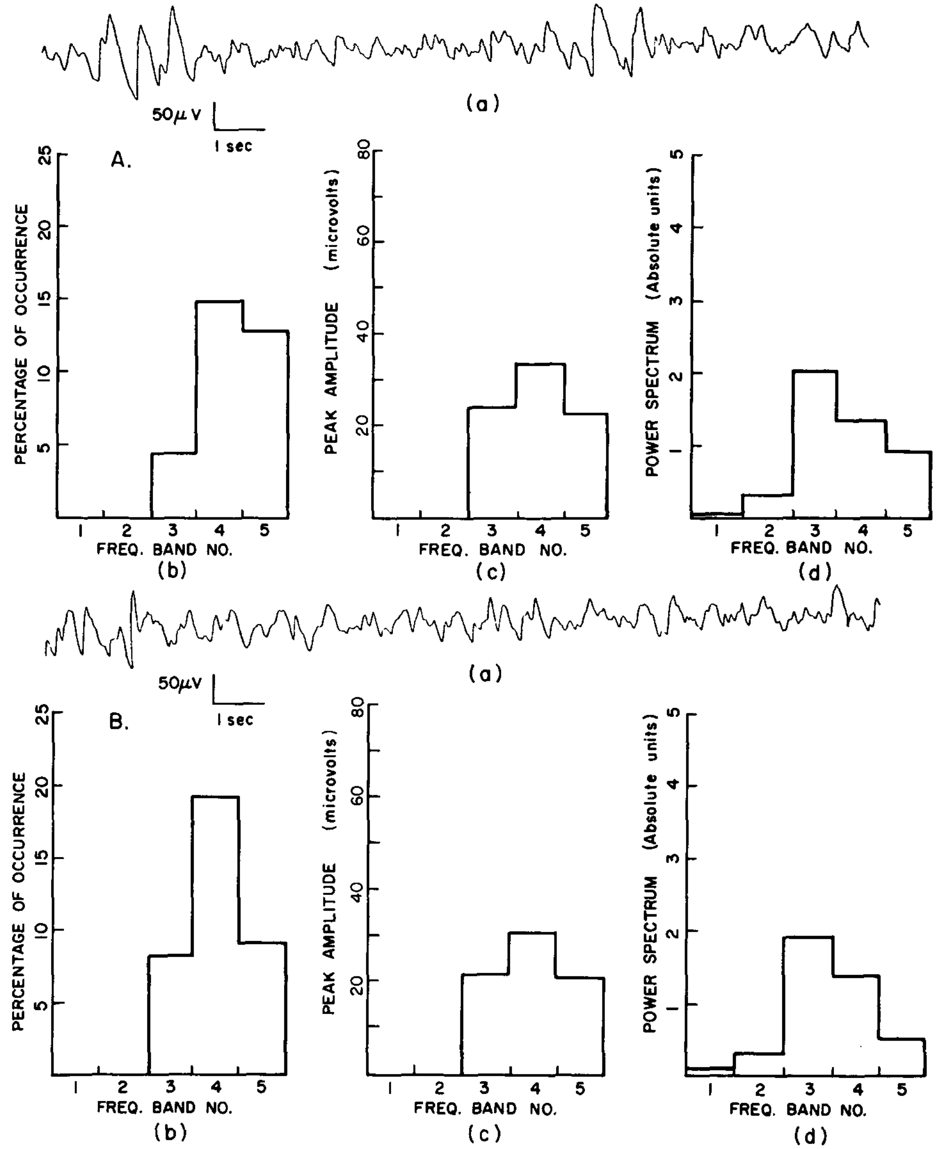

FIG. 2. Same data arrangement as in Fig. 1. Observe the similarity in the power spectrum plots of parts A and B. This similarity does not exist for the corresponding frequency bands in the percentage of occurrence plots. For both parts (A and B), observe the power content in the second frequency band of the power spectrum plot, which does not exist in the period-amplitude plots.

tional to both the incidence and amplitude of EEG activity in a particular frequency band, as expected. An example of this is shown in Fig. 4, where the power maximum at the third frequency band of the power spectrum plot seems to be the result of corresponding maxima at the same frequency band in the percentage of occurrence and mean peak amplitude plots. Also, the existence of more power in

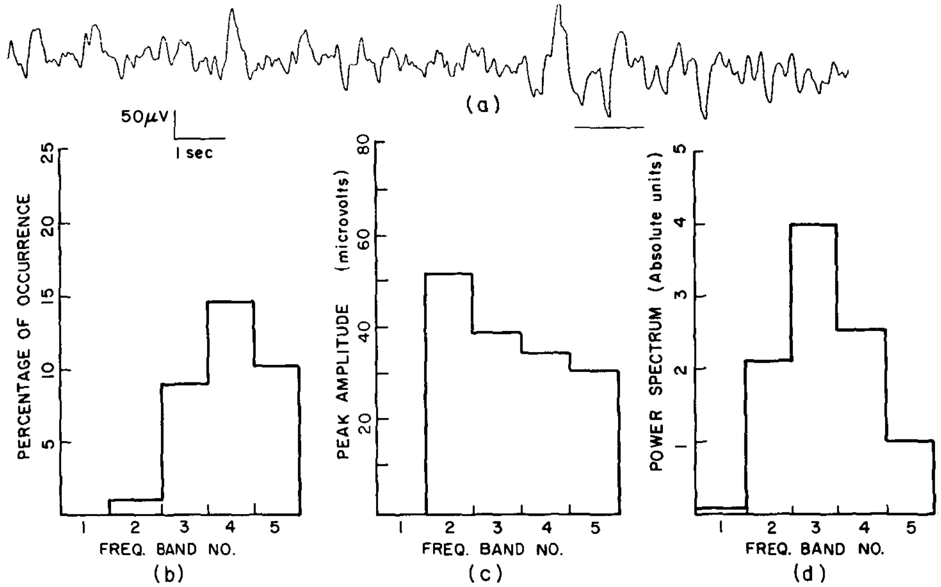

FIG. 3. Same data arrangement as in Fig. 1. Observe the activity of high amplitude and low occurrence in the second frequency band, while the fourth frequency band contains high-occurrence but low-amplitude activity. However, the power spectrum shows about equal power content in both frequency bands and cannot detect the underlined phasic EEG event, which seems to be detected by period-amplitude analysis.

the fourth than in the second frequency band of the power spectrum plot seems to be due to the higher percentage of occurrence in the fourth frequency band, since both bands exhibit similar mean peak amplitude values. However, this proportional influence of the percentage of occurrence and/or of mean peak amplitude on the power spectrum was not always that clear, as can be seen in Fig. 2A; here, the power spectrum plot shows more power in the third than in the fifth frequency band, although both bands show similar mean peak amplitudes and the third band shows a lower percentage of occurrence than the fifth one. In Fig. 2B a similar paradoxical situation exists for the same frequency bands; although they both exhibit almost the same mean peak amplitude and percentage of occurrence, their respective power content in the power spectrum plot is very different. These discrepancies can be attributed to the difference in the definition of frequency in the two methods of analysis (see Discussion).

Almost all the computed spectra showed the presence of power in the first and, especially, second frequency band. No percentage of occurrence plot showed any activity in the first band, and only about 60% of these plots showed activity in the second. In the latter case, the activity in the same band of the spectrum was proportionately much more pronounced (see Fig. 1). This can be explained by the fact that the power spectrum, resulting from a decomposition of the EEG data into their Fourier components, can quantify the power in low-frequency EEG activity which possibly exists as a slowly varying trend (i.e., variation in base-line level) in the EEG epoch, and which does not manifest itself as a visually obvious electro-

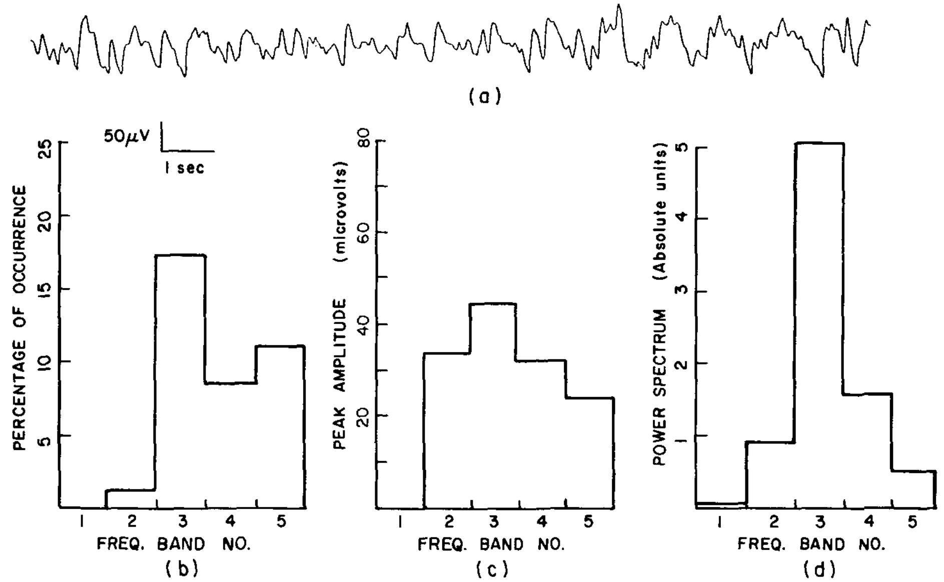

FIG. 4. Same data arrangement as in Fig. 1. Observe that the power in the power spectrum's bands is explained by taking into account the information present in the period-amplitude plots.

graphic event. On the other hand, period analysis cannot quantify such phenomena because faster events, such as well-defined delta waves, are superimposed on the slow fluctuations. These faster events provide well-defined zero-crosses, thus "masking" the slow fluctuations. Of course, the already mentioned difference in the definition of frequency in the two methods of analysis may also contribute to this discrepancy.

DISCUSSION

Both spectral and period-amplitude analyses are quantification tools that enable the investigator to estimate the "amount" of activity in various EEG frequency bands of interest. While the power spectrum efficiently quantifies overall power trends by combining incidence and amplitude information for a particular EEG frequency band, period-amplitude analysis, as presented here, seems to offer more resolution than the power spectrum in detecting electrographic details in amplitude and incidence within that EEG band. Therefore, we expect period-amplitude analysis to separate the power in a particular power spectrum frequency band to its two components, incidence and amplitude.

One of the issues raised in Results is that of the difference in the definition of "frequency" for the two techniques compared here. This difference can lead to spectral analysis showing power in frequency bands where period-amplitude analysis indicates no entry (see Fig. 2). Spectral analysis relates to a process in which one tries to fit, with the least possible error, a series of continuous (periodic) sinusoidal functions to the whole length of the data in the EEG epoch under investigation; in period-amplitude analysis, individual half- or full-waves of the

EEG are examined, one at a time, for duration and amplitude. As a result, the concept of "frequency" is different in the two techniques: in spectral analysis, by "frequency" one refers to the frequency of the periodic sinusoidal wave which is fitted to the whole length of the data, while in period analysis the term "frequency" refers to the inverse of the period between every other zero-level crossing of the EEG. This difference in definition may lead to disagreement about the amount of activity in corresponding frequency bands and about the location of maxima in the plots if an epoch is analyzed by both techniques, as shown in Results (see Figs. 2 and 3). Undoubtedly, spectral analysis may thus lead to the quantification of power in frequency bands which are not obvious from a visual analysis. For example, if one does a spectral analysis of one delta wave, which can be modeled as one-half of a sine waveform, a DC component will be obtained. Period analysis of the same delta wave will show an absence of any DC activity. Another example relates to very slow trends in the data (e.g., slow variations in base-line levels). In such cases, period analysis, relying on the presence of well-defined zero-crosses of activity superimposed on the slow trend, mimicks visual analysis and is unable to detect these slow-frequency components, which, however, will be detected by spectral analysis. Therefore, one may argue that spectral analysis is more sensitive to subtle trends in the data than is period-amplitude analysis. However, the presence of low-frequency content in the spectral plots may be misinterpreted to be due to phasic slow activity (e.g., isolated slow delta waves) rather than to a continuous slow trend, since spectral analysis cannot distinguish between the two in a satisfactory way (compare Fig. 2 to Fig. 3).

In the same vein, EEG epochs in which there exist randomly occurring amplitude discontinuities in terms of high-amplitude phasic EEG events, such as high-amplitude aperiodic delta waves, may give different results when analyzed by spectral and by period analysis techniques. This happens because the amplitude discontinuities are of pulselike nature and thus introduce harmonics of their fundamental frequency in the Fourier (spectral) domain. These harmonics are spread in adjacent spectral bands, thus contributing power which period analysis cannot quantify—"by definition." In such cases, period analysis registers only the contribution of the pulselike EEG activity's fundamental frequency, which is the inverse of the pulse's period. In addition, in these cases, spectral analysis, being an amplitude-sensitive technique, will indicate power content proportional to the phasic event's amplitude (see Fig. 3). However, if the epoch under investigation contains narrowband EEG activity of quasi-stationary, periodic nature (i.e., absence of randomly occurring phasic events) with no base-line trends, both spectral and period analysis techniques should provide similar results about the frequency content of the EEG epoch. In other words, in such cases both spectral and percentage of occurrence plots will have roughly the same range and shape, although some differences may still exist between these plots (see Fig. 4, fifth frequency band).

Our data indicated that two EEG epochs may have similar power spectra while exhibiting different electrographic morphology (see Fig. 2). This should not come as a surprise, since power spectra do not retain any phase information. Therefore, there is an infinity (at least theoretically) of time records that could correspond to a given power spectrum. In cases like the above, period-amplitude analysis seems to provide a sensitive tool for the quantification of time-domain electrographic details. For example, in Fig. 2, the two EEG epochs, although different in time structure, give rise to similar power spectra. However, although their peak amplitude plots are also similar, the corresponding percentage of occurrence plots indicate some differences. Notice that due to the inherent averaging process in the type of period-amplitude analysis presented in this paper, these differences do not correspond clearly to the visually obvious electrographic differences. Nevertheless, from the examples presented in this paper, one can conclude that period-amplitude analysis can efficiently uncouple the contribution of incidence and amplitude to the power spectrum. In cases of quasi-stationary EEG data (Figs. 1, 3, and 4), one could "synthesize" approximately the power spectrum plot from the percentage of occurrence and mean peak amplitude plots. However, when the EEG data are nonstationary in nature (e.g., presence of transients different from background or of strong and sudden modulations; see Fig. 2A), the correspondence of the power spectrum plot to the percentage of occurrence and mean peak amplitude plots is not that clear. This is due mainly to the difference in the definition of "frequency" between the two techniques, as elaborated extensively above. In some cases (see Fig. 3), period-amplitude analysis can indicate the presence of isolated events (waves) of high amplitude (phasic events) (underlined portion in Fig. 3a), while spectral analysis does not provide such a discriminatory capability. In other words, the power content in the second frequency band of Fig. 3d could have been the result of several slow delta waves, and not of just a single large one as the period-amplitude plots indicate. In fact, the power spectrum shows about equal power content in the second and fourth frequency bands, since the fourth frequency band contains higher-occurrence but relatively lower mean peak amplitude activity than the second band.

Not many authors have compared period-amplitude analysis to spectral analysis. Beatty and Figueroa (1974) analyzed short segments (1.024 sec) of awake EEG data and concluded that period analysis methods agree with spectral ones in the estimation of the percentage of power in broad EEG frequency bands of major interest (e.g., alpha and beta bands). However, theirs was a broadband analysis of quasi-stationary EEG activity devoid of phasic events and of short duration, which could lead to similar results for both period and spectral analysis methods (see above).

The usefulness of separating the incidence from the amplitude component of EEG activity in a particular frequency band, an inherent characteristic of period-amplitude analysis, has been emphasized by many investigators. Kardel and Stigsby (1975) showed that the amount of EEG activity as given by period analysis changed in some frequency bands when passing from control subjects to patients suffering from cirrhosis of the liver. Amplitude measurements in those frequency bands yielded little useful information. Carrie and Frost (1973) reported an increase in the number of waves in the beta-frequency band of the EEG during administration of flurazepam hydrochloride, with no detectable change in mean wavelength (period) or mean amplitude of EEG full-waves. In a similar vein, Feinberg et al. (1977) found that only amplitude-free measurements of the period of EEG half-waves in the delta-frequency band showed the effect of flurazepam on the delta activity during sleep.

Some authors have reported on the degree of agreement of visual analysis to period-amplitude and spectral analysis methods as applied to narrowband EEG data. Feinberg et al. (1978) showed that period-amplitude analysis can confirm observations based on visual analysis, in that the decline in the visually scored sleep stages 3 and 4 with age is actually produced by a decline in the delta amplitude and density, specifically by a decline in the number of delta waves in the slower end of the delta band. Similar results were given by Smith et al. (1977), who also used period-amplitude analysis in the delta-frequency band of the sleep EEG and found that the delta-wave amplitude, as well as the incidence of delta waves above a certain peak amplitude, decreases with age. Isaksson and Wennberg (1975) compared visually evaluated slow activity (VESA) in the EEG, described as a broadband signal within the delta EEG band, and its corresponding spectral signature. They found a linear correlation between the degree of VESA and the bandwidth and power of the delta spectral frequency band. However, no detailed analysis of the slow activity was attempted.

The use of broadband spectral analysis for automated EEG processing is justified, since it provides rough information about the overall power of the EEG data in broad frequency bands that are similar to those of the visual analysis (Bickford, 1977; Bickford et al., 1973). However, further detailed processing (e.g., sleep EEG staging) based on spectral estimates may not correspond to visual analysis (Smith, 1978). If the temporal composition of the EEG patterns in terms of detailed characteristics of periods and amplitudes within a particular frequency band (e.g., delta band) is an important aspect of the EEG quantification, then period-amplitude analysis, as presented in this paper, although it may not contain all the gestalt information existing in the original raw EEG data, seems to be preferable to narrowband spectral analysis. Although period-amplitude analysis involves averaging within the data window of observation in terms of estimating percentages of occurrence and mean peak amplitudes and arranging these into artificially created frequency bins, the resulting histograms seem to preserve more detailed information about the EEG time history than the corresponding spectral plots, especially by separately quantifying the incidence of EEG half-waves and their respective peak amplitudes. In addition, the combined use of occurrence and peak amplitude plots seems to offer a method for detecting isolated phasic events of high amplitude, as shown in Fig. 3, where the underlined EEG portion contributes a low entry in the second frequency band of the occurrence plot but a high entry in the same band of the amplitude plot. However, this method breaks down when additional events of similar duration but smaller amplitude exist in the data. In such cases, the averaging process will decrease the contribution of the phasic event to the peak amplitude histogram, and period-amplitude analysis, as well as spectral analysis, will not be able to detect its presence.

ACKNOWLEDGMENT

The authors are grateful to I. Karacan, M.D., Director of the Sleep Disorders Center, Baylor College of Medicine, Texas Medical Center, Houston, Texas, for providing sleep EEG data.

REFERENCES

Barlow JS. Computerized clinical electroencephalography in perspective. *IEEE Trans Biomedical Engin* 26:377–391, 1979.

Barr RE, Ackmann JJ, and Sonnenfeld J. Peak-detection algorithm for EEG analysis. *Int J Biomed Comput* 9:465–476, 1978.

Beatty J and Figueroa C. Periodic analytic algorithms for the estimation of selected spectral properties of short segments of EEG data. *Behav Res Methods Instrum* 6:293–295, 1974.

Bendat JS and Piersol AG. *Random Data: Analysis and Measurement Procedures.* Wiley, New York, 1971.

Bickford RG. Computer analysis of background activity. In: A Rémond (Ed), *EEG Informatics. A Didactic Review of Methods and Applications of EEG Data Processing.* Elsevier/North-Holland Biomedical Press, Amsterdam, 1977.

Bickford RG, Brimm J, Berger L, and Aung M. Application of compressed spectral array in clinical EEG. In: P Kellaway and I Petersén (Eds), *Automation of Clinical Electroencephalography,* Raven Press, New York, 1973.

Bremer G, Smith JR, and Karacan I. Automatic detection of the K-complex in sleep electroencephalograms. *IEEE Trans Biomed Engin* 17:314–323, 1970.

Burch NR, Nettleton WJ Jr, Sweeney J, and Edwards RJ Jr. Period analysis of the electroencephalogram on a general-purpose digital computer. *Ann NY Acad Sci* 115:827–843, 1964.

Carrie JRG. Zero-cross EEG analysis: Effects of noise. *Int J Biomed Comput* 4:97–103, 1973.

Carrie JRG and Frost JD Jr. Wavelength-amplitude profile analysis in clinical EEG. In: P Kellaway and I Petersén (Eds), *Automation of Clinical Electroencephalography,* Raven Press, New York, 1973.

Dolce G and Künkel H (Eds). *CEAN-Computerized EEG Analysis.* Gustav Fischer-Verlag, Stuttgart, 1975.

Dumermuth G, Gasser T, and Lange B. Aspects of EEG analysis in the frequency domain. In: G Dolce and H Künkel (Eds), *CEAN-Computerized EEG Analysis,* Gustav Fischer-Verlag, Stuttgart, 1975.

Feinberg I, Fein G, Walker JM, Price LJ, Floyd TC, and March JD. Flurazepam effects on slow-wave sleep: Stage 4 suppressed but number of delta waves constant. *Science* 198:847–848, 1977.

Feinberg I, March JD, Fein G, Floyd TC, Walker JM, and Price L. Period and amplitude analysis of 0.5–3 c/sec activity in NREM sleep of young adults. *Electroencephalogr Clin Neurophysiol* 44:202–213, 1978.

Gevins AS, Yeager CL, Diamond SL, Spire JP, Zeitlin GM, and Gevins AH. Automated analysis of the electrical activity of the human brain (EEG): A progress report. *Proc IEEE* 63:1382–1399, 1975.

Isaksson A and Wennberg A. Visual evaluation and computer analysis of the EEG—A comparison. *Electroencephalogr Clin Neurophysiol* 38:79–86, 1975.

Kardel T and Stigsby B. Period-amplitude analysis of the electroencephalogram correlated with liver function in patients with cirrhosis of the liver. *Electroencephalogr Clin Neurophysiol* 38:605–609, 1975.

Kellaway P and Petersén I (Eds). *Automation of Clinical Electroencephalography.* Raven Press, New York, 1973.

Kellaway P and Petersén I (Eds). *Quantitative Analytic Studies in Epilepsy.* Raven Press, New York, 1976.

Ktonas PY and Smith JR. Automatic REM detection: Modifications on an existing system and preliminary normative data. *Int J Biomed Comput* 9:445–464, 1978.

Rémond A (Ed). *EEG Informatics. A Didactic Review of Methods and Applications of EEG Data Processing.* Elsevier/North-Holland Biomedical Press, Amsterdam, 1977.

Schenk GK. The pattern-oriented aspect of EEG quantification. Model and clinical basis of the iterative time-domain approach. In: P Kellaway and I Petersén (Eds), *Quantitative Analytic Studies in Epilepsy,* Raven Press, New York, 1976.

Sharp FH, Smith GW, and Surwillo WW. Period analysis of the electroencephalogram with recording of interval histograms of EEG half-wave durations. *Psychophysiology* 12:471–475, 1975.

Smith JR. Computers in sleep research. *CRC Crit Rev Bioengin* 3(2):93–148, 1978.

Smith JR, Funke WF, Yeo WC, and Ambuehl RA. Detection of human sleep EEG waveforms. *Electroencephalogr Clin Neurophysiol* 38:435–437, 1975.

Smith JR, Karacan I, and Yang M. Ontogeny of delta activity during human sleep. *Electroencephalogr Clin Neurophysiol* 43:229–237, 1977.

Stigsby B, Obrist WD, and Sulg IA. Automatic data acquisition and period-amplitude analysis of the electroencephalogram. *Comput Programs Biomed* 3:93–104, 1973.

Williams RL, Karacan I, and Hursch CJ. *Electroencephalography (EEG) of Human Sleep: Clinical Applications*. Wiley, New York, 1974.