Medical and Biological Sciences, 2013, 27/1, 53-57

ORIGINAL ARTICLE / PRACA ORYGINALNA

Tadeusz Pracki[1], Monika Wiłkość[2,3], Daria Pracka[1]

PRESENTATION OF POLYSOMNOGRAM BY COLOR VOLTAGE ARRAY

PREZENTACJA POLISOMNOGRAMU PRZY UŻYCIU METODY COLOR VOLTAGE ARRAY

[1]Department of Physiology, Nicolaus Copernicus University, Ludwik Rydygier Collegium Medicum in Bydgoszcz
Head: prof. dr hab. med. Małgorzata Tafil-Klawe
[2]Institute of Psychology, Kazimierz Wielki University in Bydgoszcz
Head: prof. dr hab. Janusz Trempała
[3]Department of Psychiatry, Nicolaus Copernicus University, Ludwik Rydygier Collegium Medicum in Bydgoszcz
Head: prof. dr hab. med. Aleksander Araszkiewicz

Summary

The paper contains a description of the original technique known as the Color Voltage Array (CVA) used for graphic presentation of EEG signal for both polysomnographic and EEG research.

CVA uses color to present electrical voltages of particular waves in the EEG recordings calculated through the Fast Fourier Transform (FFT). The overnight sleep records of 56 healthy volunteers of both sexes (42 women, 14 men; aged 19-27) were analyzed in order to verify the CVA technique. The obtained results confirm the applicability of the CVA technique to the analysis of the human sleep. For analysis of the sleep process, the authors suggest using the Color Voltage Array technique together with a traditional hypnogram. The informative value of a hypnogram increases significantly when combined with CVA.

Streszczenie

W pracy opisano oryginalną technikę Color Voltage Array (CVA) graficznej prezentacji sygnału EEG, do zastosowań zarówno w badaniach polisomnograficznych jak i w badaniach EEG. CVA prezentuje kolorowo zawartość napięć elektrycznych poszczególnych fal w zapisie EEG, obliczonych przy użyciu szybkiej transformaty Fouriera (FFT).

W celu weryfikacji proponowanej techniki CVA, przebadano całonocne zapisy snu 56 zdrowych ochotników obojga płci (42 kobiety, 14 mężczyzn), w wieku 19-27 lat. Uzyskane wyniki potwierdzają przydatność techniki w analizie przebiegu polisomnograficznego snu człowieka.

Autorzy proponują stosowanie w analizie przebiegu snu techniki Color Voltage Array wraz z tradycyjnym hipnogramem. Wartość informacyjna hipnogramu w połączeniu z CVA znacznie wtedy wzrasta.

Key words: sleep, EEG, spectral analysis, power density, FFT, root mean square voltage, color voltage array
Słowa kluczowe: sen, EEG, analiza widmowa, widmo mocy, FFT, napięcie skuteczne

INTRODUCTION

The polysomnogram is a routine recording of the human sleep run with at least electroencephalograms (EEG), electrooculograms (EOG) and electromyogram (EMG) derivations. It is presented through hypnogram which is a graphical representation of sleep.

It has become an international language among sleep researchers. Hypnogram presents awakening and four stages of sleep - three Non-Rem (N1, N2, N3) and REM (R) [1]. Despite its simplicity, hypnogram bears

a lot of disadvantages. It is difficult to present the complicated, dynamic intracerebral processes that occur during sleep via several numbers especially among people with sleep disorders. The simplifications applied when creating a traditional hypnogram are paid for dearly with a loss of parts of information included in the polysomnogram which are often of great importance. Therefore, another presentation of the process of human sleep that is going to be more accurate but simple at the same time seems advisable. . That has become possible with the use of the spectral analysis of signals in sleep research.

The beginnings of the spectral analysis date back to 1822, when Fourier described the basics of mathematical analysis of functions later known as the Fourier's spectral analysis [2]. The fundamental apparatus of the mathematical spectral analysis of signals is the Fourier series and the Fourier transform. The Fourier series are applied to periodic oscillations. However, for more complex oscillations, including EEG, the Fourier transform is more adequate.

The first person to apply the Fourier transform to record the human EEG was Dietsch (1932) [3]. He made hand-written copies of recordings largely magnified through epidiascope. With the use of a ruler, he measured the parameters of the obtained curves and calculated the coefficients of the Fourier transform. He observed higher frequencies which were not earlier known in an EEG recording.

In 1938 Grass and Gibbs applied the Fourier transform in the analysis of electroencephalogram using their own, complicated, Grass' electromechanical integrator [4]. In 1942 such an integrator was used for the first time to examine human sleep by Knott et al. [5].

Through the following years the spectral analysis of EEG was nowhere to be practically applied. It was caused by the measurement difficulties and the necessity of using specialist, complex and expensive devices.

The spectral analysis of EEG was used again in 1965 by Hord et al. [6]. It was a digital Fourier analysis carried out with the use of a large, expensive and, unfortunately, very slow computer.

A significant breakthrough in the power spectral analysis of the signals took place after 1965, when Colley and Tukey developed the fast Fourier transform algorithm (FFT), which was a modification of the Fourier transform algorithm that considerably shortened the time of the calculations [2]. With the employment of fast Fourier transform FFT and new, fast and cheap computers the spectral analysis has become widely accessible for sleep researchers, also online.

In 1991 the European Sleep Research Society published a Consensus Report [7]. The authors underline the superiority of the automatic analysis over the visual one, especially with regards to the slow wave sleep stage (former S3 and S4 stages, currently N3). They claimed that in pharmacology for the sleep presentation both hypnogram and the power spectrum of EEG signal must be used. Additionally, they advised using the spectral analysis for the physiological sleep research.

It should not be omitted that there exist other methods of signals spectral analysis [8], however the Fast Fourier Transform is the most commonly used in the EEG examinations.

The application of spectral analysis in the research of sleep allowed different ways of presenting EEG.

One of the first techniques of displaying the power spectrum of EEG signals was the Compressed Spectral Array (CSA) presented by Bickford and Billinger [9]. Via a pseudo-three-dimensional way, it showed the results of the FFT analysis in the form of the power of EEG signal in a function of its frequency for consecutive epochs of sleep recordings. Although the results of the power spectrum were fully displayed, the technique was difficult for interpretation and applied practically for the reason of their number (the presentation of an overnight recording contained nearly 1000 diagrams). Similar was the case of a later, simplified, two-dimensional version – Density Spectral Array (DSA) [10].

Salinsky et al. (1987) presented the Color Density Spectral Array (CDSA) - a multicolor, graphic representation of sleep [11]. They followed the idea of an EISA-gram described in 1968 by Tönnies who showed dominant frequencies in an EEG recording [12]. In the CDSA technique, Salinsky et al. [11] used the spectral analysis of an EEG from a polysomnogram. Using FFT they calculated the power spectra of the registered signals. The results were presented graphically in a form of frequencies marked with various colors depending on the power of the signal. The representation of sleep with the use of CDSA was not legible enough; therefore, it has not gained popularity. The technique of CDSA was modified by Pracki et al. (2008) and owing to that it has became much more accurate and legible [13].

However, it still contained simplifications and showed the power spectrum in a partial way.

The authors suggest their own, original and accurate but at the same time simple way of presenting EEG signals – Color Voltage Array (CVA) which uses the spectral analysis FFT of the polysomnogram EEG signals.

MATERIAL AND METHODS

In this research an overnight sleep recordings on 56 healthy volunteers of both sexes (42 women and 14 men) at the age of 19-27 (mean 23.58; SD 2.88) were conducted.

It used the polysomnogram computer analysis system – Somnoscan Plus [14, 15] to register two EEG derivations (C3-M2, C3-01), two EOG derivations for the left and right eye as well as one submental EMG derivation.

The recordings of 30-seconds, 49572 epochs polysomnographic were visually analyzed and hypnograms were created [1, 16, 17].

Next, the obtained hypnograms were used for the computer spectral analysis of EEG signal. For the C3-M2 derivation (former C3-A2), sampled with the frequency of 120 Hz and resolution 12 bits, the power spectra were calculated through fast Fourier transform FFT for 5-second blocks of data with a resolution of 0.2 Hz. The power of each 30-second epoch of the polysomnogram was counted out of the six 5-second blocks of data with the application of segmental smoothing in order to improve the accuracy of the analysis. In order to diminish the blur of the function of not overlaying, Hann's window was employed [15, 18].

The power of EEG signal was counted within the range of the following waves: delta - δ (0.4-4.0 Hz), theta - σ (4.0-8.0 Hz), alpha - α (8.0-12.0 Hz), sigma - σ (12.0-14.0 Hz) and beta - β (14.0-25.0 Hz). For the successive epochs of polisomnograms, root-mean-square (rms) voltages were calculated which (wave range). The rms voltages were the square root of the EEG signal power. Such procedure was applied in order to increase the legibility of the results. Otherwise the small indexes would be practically unnoticeable [13, 15] . Similar results may have been obtained through the logarithmic scale; however the interpretation would be significantly more complicated. The total rms voltage was calculated as a square root of the total power of EEG signal for all the examined epochs of polysomnogram. The ratio of particular ranges wave voltages to the total EEG voltage of epochs was calculated as a percentage of the voltage of given waves out of the total EEG signal.

RESULTS

Cumulated stripes with the percent value of voltage for a given epoch were drawn for successive waves beginning with the waves of the lowest frequency and marked with experimentally accepted colors: delta – blue, theta – light blue, alpha – red, sigma – yellow and beta – green. First, the blue stripe for delta waves was drawn beginning from the lowest and moving to the highest values. Then the next wave - light blue stripe for theta waves towards higher values beginning from the end of the previous wave – delta waves stripe etc. to finally obtain the value of 100% (Fig. 1).

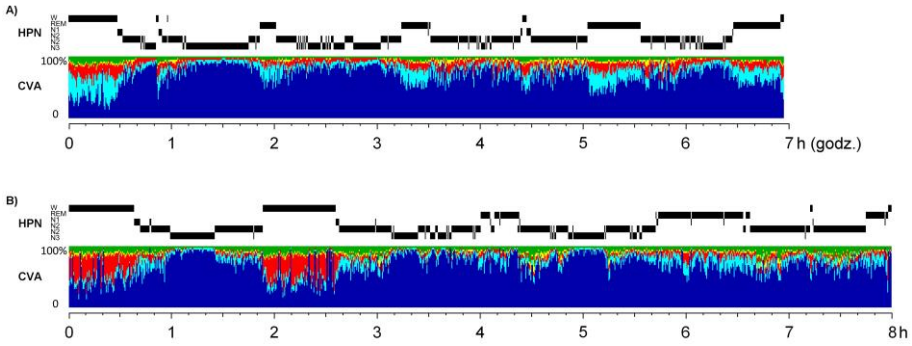

Fig. 1. *Example overnight hypnograms (HPN) and the corresponding Color Voltage Array (CVA) displays of the C3-M2 derivations: (A) of a healthy adult (female); (B) of an adult (male) suffering from insomnia. X axis – time of the recording (EEG waves markings: delta – blue, theta – light blue, alpha – red, sigma – yellow and beta – green; descriptions are in the text)*

Ryc. 1. *Przykładowy całonocny hipnogram (HPN) oraz przebieg Color Voltage Array (CVA) dla odprowadzenia C3-M2: (A) dorosłej, zdrowej kobiety; (B) dorosłego mężczyzny cierpiącego na bezsenność. Oś X – czas rejestracji (fale EEG oznaczono: delta – niebieski, theta – jasno niebieski, alpha – czerowny, sigma – żółty i beta – zielony; opis w tekście)*

Figure 1 shows example hypnograms and corresponding Color Voltage Array presentation (C3-M2) of a healthy adult (female, 22 years old) (Fig. 1A) and an adult (male, 27 years old) suffering from insomnia (Fig. 1B). In both cases the accordance of the CVA displays and their hypnograms is clearly legible.

During the awakening stage (W) there is a higher amount of alpha (red) and theta (light blue) waves, whereas during REM stage the amount of alpha (red) and theta (light blue) waves decreases. With the sleep getting deeper (stages N2 and N3) there is a noticeable increase in the amount of delta waves (blue) and decrease in beta waves (green). Also, the beginning and ending of sleep is clearly legible (Fig. 1B).

In order to verify the correctness of the sleep presentation with the use of the suggested CVA technique, it was examined whether the voltages of the successive ranges of waves differ in particular stages of sleep and awakening. Statistical *t*-student tests were applied in this examination [19]. The calculated percent values of EEG waves voltage and the number of epochs for particular stages are presented in Table 1.

Table I. *Percent values (Mean; SD) of the EEG waves voltages for particular stages of sleep and awakening (n – number of epochs; descriptions are in the text)*
Tabela I. *Wartości procentowe (średnia, SD) napięcia elektrycznego fal EEG dla poszczególnych stadiów snu oraz czuwania (n – liczba składek; opis w tekście)*

Waves % Zawartość fal %	Stages Stadia				
	W	R	N1	N2	N3
Delta	44.72±21.74	63.36±11.63	63.06±15.39	71.57±11.95	89.52±5.07
Theta	16.60±10.82	20.18±6.95	16.21±8.07	13.78±5.89	6.62±3.00
Alpha	25.44±15.74	9.83±5.91	12.04±8.54	7.25±4.33	2.29±1.75
Sigma	3.66±2.26	2.31±1.29	2.81±1.89	5.07±4.78	0.95±0.88
Beta	9.59±6.59	4.32±2.79	6.37±4.96	2.35±2.38	0.62±0.73
n	3942	10672	1295	24119	9544

For the delta waves (δ) voltages, there are statistically significant differences among their average values (*t* for average values, $P<0.001$) for every stage excluding the relation between N1 and R.

For the theta waves (σ), there are statistically significant differences among the average values (*t* for average values, $P< 0.001$) for every stage excluding the relations between the awakening and the stage N1. Comparably for alpha (α), sigma (σ) and beta (β) waves, there were statistically significant differences in average values (*t* for average values, $P<0.001$) between the awakening and other sleep stages.

DISCUSSION

The results obtained demonstrate the significant differences in quantity of particular waves between stages of sleep and awakening.

It must be noted that the differentiation between N1, REM stages and awakening is hampered in both the visual and the computer analysis due to the similarity of the stages. On the other hand, the N1 stage covers only a few percent of the total sleep period and is unimportant from the analytical perspective.

The traditional hypnogram shows only 5 stages, whereas the voltages of EEG in the presented CVA technique may take a wider range of values between 0-100% in many various combinations.

CONCLUSIONS

The obtained results fully confirm efficiency of the Color Voltage Array technique in the presentation of human sleep polisomnogram. The CVA displays human sleep in accordance with the original hypnogram but including incomparably more information about the sleep run than the hypnogram itself. After viewing the CVA, an expert has the exact picture of the whole sleep much closer to the reality than in a traditional hypnogram. On the basis of the obtained results, the authors suggest using the Color Voltage Array together with the hypnogram. The informational value of the hypnogram in combination with the CVA increases significantly. Moreover, the CVA technique may be useful for presentation of the human routine EEG.

REFERENCES

1. Iber C, Ancoli-lsrael S, Chesson A, Quan SF (2007) for the American Academy of Sleep Medicine. The AASM Manuał for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications. American Academy of Sleep Medicine. Westchester, Illinois,
2. Lyons RG (2000) Understanding Digital Signal Processing (in Polish). WKŁ, Warsaw.
3. Dietsch G (1932) Fourier-analyse von Elektrenkephalogrammen des Menschen. Pflüger's Arch Ges Physiol 230: 106-112.
4. Grass AM, Gibbs FA (1938) A Fourier transform of the electroencephalogram. J Neurophysiol 1: 521-526.
5. Chase MH (ed.) (1972) Computers in Sleep Research (The Sleeping Brain). Perspectives in the Brain Sciences. BIS, BRI University of California. Los Angeles. 277-321.
6. Hord DJ, Johnson LC, Lubin A, Austin MT (1965) Resolution and Stability in the Autospectra of EEG. Electroenceph clin Neurophysiol 19, 305-308.
7. Borbély AA, Äkerstedt T, Benoit O, Holsboer O, Oswald I (1991) Hypnotics and sleep physiology: a consensus report. Eur Arch Psychiatry Clin Neurosci 241: 13.21.

8. Sanei S, Chambers J (2007) EEG signal processing. John Wiley and Sons Ltd. The Atrium, Southern Gate, Chichester, West Sussex.
9. Bickford RG, Billinger TW, Fleming NI, Steward F (1972) The compressed spectral array (CSA): A pictorial EEG. Proc San Diego Biomed Symp 11: 365-70.
10. Niedermeyer E , Lopes da Silva FH (1993) Electroencephalography: Basic Principles, Clinical Applications, and Related Field. Williams nad Wilkins Baltimore, Maryland.
11. Salinsky M, Sutula T, Roscoe D (1987) Representation of sleep stages by color density spectral array. Electroenceph Clin Neurophysiol 66: 579-582.
12. Tönnies JF (1969) Automatische EEG Internall Spectrumanalyse (EISA) zur Langzeitdarstellung der Schlafperiodik und Narkose. Arch Psychiat Nervenkr 212: 423-455.
13. Pracki T, Pracka D, Ziółkowska-Kochan M, Tafil-Klawe M, Szota A , Wilkość M (2008) The modified Color Density Spectral Array – an alternative method for sleep presentation. Acta Neurobiol Exp 68: 516-518.
14. Pracki T, Zając J, Kowalski W, Kucharz E, Jurek K, Pracka D, Narębski J (1990) SOMNOSCAN Expert System for Analysis of Sleep (in Polish). Probl Techn Med 21: 38 50.
15. Pracki T, Pracka D, Szulc K, Ziółkowska-Kochan M, Tafil-Klawe M (2009) Polysomnography. Introduction to EEG spectral analysis (in Polish). Sen 9 (1-2), 31-36.
16. Rechtschaffen A, Kales A (Ed.) (1968) A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. DHEW, Publication No. (NIH) 204, U.S. Government Printing Office, Washington.
17. Webb WB (1986) Recording methods and visual scoring criteria of sleep records: Comments and recommendations. Perceptual and Motor Skills 62: 664 666.
18. Pracka D, Pracki T (1996) Spectral analysis in cyclic changes of human sleep evaluation. Acta Neurobiol Exp 56: 255-258.
19. StatSoft. Inc. (2008) Statistica (data analysis software system). v. 8.0. (licence for Collegium Medicum in Bydgoszcz).

Address for correspondence:
Tadeusz Pracki
Katedra Fizjologii
Collegium Medium
ul. Karłowicza 24.
85-092 Bydgoszcz
tel.: 602-841-889
fax: (52) 585-37-23
e-mail: prackie@wp.pl
internet: www.sen.bydgoszcz.pl

Received: 4.12.2012
Accepted for publication: 5.02.2013