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The modified Color Density Spectral Array – an alternative method for sleep presentation

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The modified Color Density Spectral Array (CDSA) method used for graphical representation of sleep patterns is described in this article. CDSA was presented for the first time in 1987 by M. Salinsky and coauthors. This method was adapted to display frequency course and voltage of EEG signal during sleep. The overnight sleep records of 35 healthy volunteers of both sexes (23 women, 12 men; aged 19–26) were analyzed in order to verify the modification of CDSA method. We propose to use combining the hypnogram and CDSA method significantly increases the informative value of data and results in enhanced quality of sleep analysis.

Key words: sleep, color density spectral array, CDSA, EEG, spectral analysis

The hypnogram is a conventional, graphical presentation of sleep, which became an international standard among sleep researchers. The hypnogram is based on the analysis of polysomnographic records which contain at least one EEG lead, one EMG lead, and EOG leads for left and right eyes. The advantage of the hypnogram is its 7-stage sleep representation that makes this method easy to read and use (Rechtschaffen and Kales 1968, Webb 1986). However, the hypnogram also has disadvantages. It is difficult to display the complicated dynamic stochastic processes appearing in the polysomnograph by using only seven stages. Simplifications in the traditional hypnogram cause the loss of some valuable information contained in the polysomnograph, hence a more precise display of sleep is recommended (Kuś et al. 2006).

The first colorful graphical sleep representation obtained by using CDSA method was presented by M. Salinsky and colleagues in 1987 and 1988. It seems that Tönnies' EISA-gram (Tönnies 1969, Beck and Kendel 1971) was a prototype of CDSA, however the authors never mentioned it. They used spectral analysis of polysomnographic signals and, by means of Fast Fourier Transform (FFT), they counted the power spectrum of the registered signals. The frequencies were represented graphically in different colors, in accordance with the power of the signal. Each color corresponded to a different power. If the signal's power for that particular frequency exceeded its threshold value, it was indicated by the corresponding color on CDSA. The CDSA sleep representation was difficult to interpret and made this method unpopular.

In this study we proposed a novel way of EEG signal representation by means of a modified CDSA method (Pracka and Pracki 1996). The number of colors was reduced to three: red, blue and yellow. Also, there were dynamically varying thresholds for particular colors. Relative values of threshold matching a percentage value of root-mean-square voltage of EEG, counted for each epoch of the polysomnogram, were chosen. Voltage of EEG (rms) counted for the analyzed epoch of the polysomnogram was treated as 100%.

A different percentage value of the relative threshold power of EEG was associated with a particular color. If the signal voltage for any frequency counted

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for one epoch of the polysomnogram exceeded one of the three threshold values, it was marked on the graph by a particular color. The graph plotting started from frequencies matched with the lowest threshold value.

Overnight sleep records of at least 8 hours duration of 35 healthy volunteers of both sexes (23 women, 12 men), aged 19–26 (mean 23.09; SD 2.08) were analyzed. The recordings were made after one night of subjects' adaptation to laboratory conditions. The aim of this study was to verify the sleep representations obtained by modified CDSA method.

The polysomnographs from two leads of EEG (C3–A2; C3–01), leads for the left and the right eyes, and chin lead were registered.

The recordings of 30 seconds polysomnographic epochs were visually analyzed in accordance with Rechtschaffen and Kales rules (Rechtschaffen and Kales 1968) and by Somnoscan Plus computer system (Pracki et al. 1990, 1996). The visual hypnograms for all polysomnographs were created using this method. 32 603 epochs of the polysomnogram containing 2010 epochs of wakefulness, 707 epochs of Movement Time, 6 993 epochs of REM sleep, 721 epochs of stadium 1, 16 142 epochs of stadium 2, 4 161 epochs of stadium 3, and 1 869 epochs of stadium 4 were analyzed. Spectra of the power for EEG signal coming from C3–A2 leads were counted by using Fast Fournier Transform (FFT). For each 30-second epoch of the polysomnogram, divided on six 5-second data blocks, power densities were computed with 0.2 Hz resolution, then smoothed and averaged (Otnes and Enochson 1978, Pracka and Pracki 1996, Lyons 2000, Wyczesany 2008). Afterwards, the rms voltage which is a square root of the power of EEG signal was counted. Resolution for CDSA was empirically selected as 0.6 Hz by averaging three power density intervals of 0.2 Hz width.

Values of the threshold power for CDSA changed from 10–90% with an increment of 10%. The values which allowed the accurate sleep representation were chosen. Numbers from 1 to 7 were associated with different hypnogram stages, according to their position on the hypnogram. Number 7 was associated with Movement Time (MT), 6 with wakefulness, 5 with REM sleep, 4–1 with 1–4 NREM stadiums. The frequencies of the selected threshold values presented on the modified CDSA were tested to verify whether they allow differentiation between the sleep and wakefulness stages.

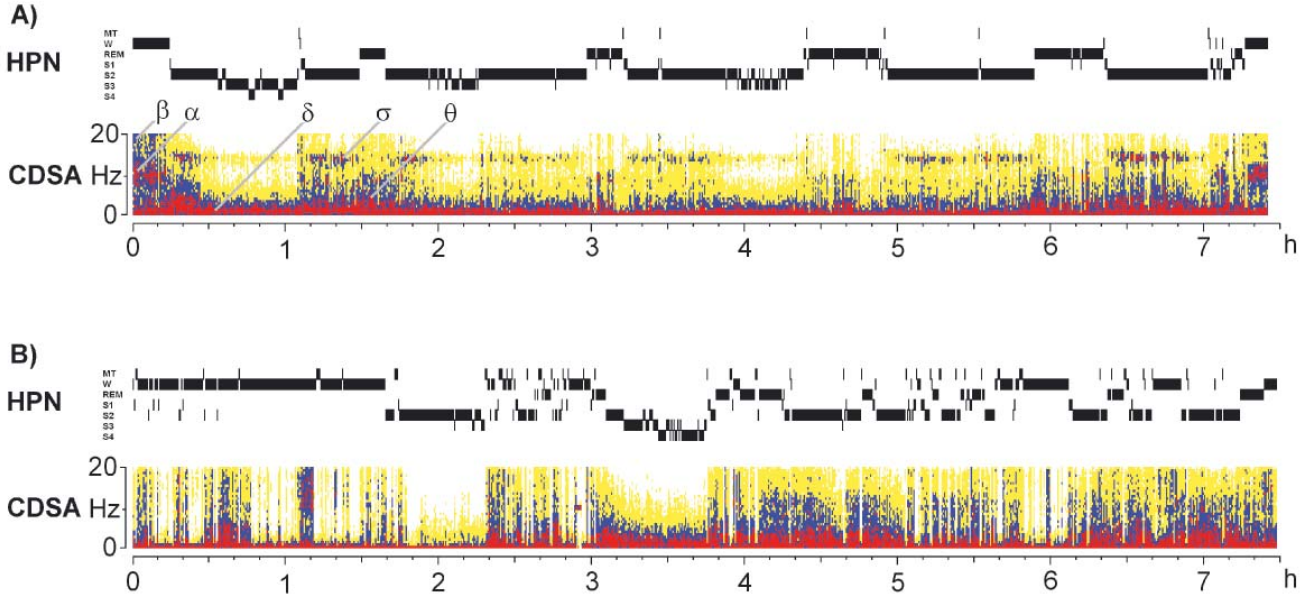

Fig. 1. Examples of the hypnograms – HPN (in sleep stages) and modified Color Density Spectral Arrays – CDSA (in Hz): (a) in a healthy, adult person; (b) in an adult person suffering from insomnia (horizontal axis in sleep hours). The CDSA intensity scale was coded by colors (red the strongest, blue and yellow). The alpha (α) and beta (β) waves dominate in the stage of wakefulness (W). During deep sleep (stages S3–S4) the delta (δ) waves are dominant. The sleep spindles (σ) are specific for the S2 stadium, whereas the theta (θ) waves are specific for REM stadium.

Correlations between frequencies of the EEG signals presented on the modified CDSA and the hypnograms were investigated.

The corresponding voltage thresholds for three colors were 10, 30, and 60%, which allowed the best representation of the sleep. The frequencies of EEG signals presented on the modified CDSA allowed discrimination of each voltage threshold (t for average values, $P<0.001$) (Greń 1975). However, the differences between stadium 1 NREM and REM are not statistically significant at the voltage threshold of 60%.

The correlation coefficients (r) between all the hypnograms and frequencies matched with particular threshold values for CDSA for all sleep and wakefulness stages were counted (Greń 1975, Otnes and Enochson 1978). Values for correlation coefficients were obtained as follows: $-r_{10}=0.70$, for the level of 10% (t, $P<0.001$); $-r_{30}=0.42$, for the level of 30% (t, $P<0.001$); $-r_{60}=0.35$, for the level of 60% (t, $P<0.001$).

Results of statistical tests indicated that a positive correlation coefficient between the hypnograms and frequencies presented for CDSA differs from 0 (t, $P<0.001$). It means that the data obtained by using modified CDSA method is statistically correlated with stages on the hypnogram.

Figure 1 shows the hypnograms and corresponding graphs of modified CDSA (lead C3–A2): (a) of a healthy, adult person and (b) of an adult person suffering from insomnia. In these figures consistency of modified CDSA representations with corresponding hypnograms is distinctly visible. The increase in sleep depth is connected with the decrease in frequencies associated with particular colors on CDSA. The alpha (α) waves (8.0–12.0 Hz) and beta (β) waves (16.0–20.0 Hz) dominate in the stage of wakefulness – W. During deep sleep (stages S3–S4) the delta (δ) waves (0.6–2.0 Hz) are dominant. The spindles (σ; 12.0–16.0 Hz) are specific for the second stadium – S2, whereas the theta (θ) waves (4.0–8.0 Hz) are specific for REM stadium.

These data markedly revealed that the modified CDSA method used in this study provides significantly more information about sleep than the hypnogram (Fig. 1) and allows more precise analysis of the sleep data. This study demonstrated that the modified CDSA method proposed by the authors is more reliable and easier for interpretation.

In conclusion, the authors think that combining the modified CDSA method with the traditional hypnogram results in enhanced quality of sleep analysis.

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