EEG Cartography of a Night of Sleep

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Quantitative analysis of EEGs has been applied since 1932 by using Rourier spectral analysis. However, it is only in 1963 that D.C. Walter was able to use Fast Fourier Transform algorithm (FFT) for computing power spectra. With the introduction of mini- and micro-computers, spectral analysis of EEG has been extensively developed. First, it was used for clinical pathology and pharmaco-EEG research. More that 800 references and almost 15 books are indicative of this growing trend. Quantitative EEG analysis was first applied to a few EEG channels. Pioneers like A. Remond in Paris, H. Petsche in Vienna, D. Lehmann in Zurich, have published articles on brain electrical field distributions over the scalp, applying quantitative EEG techniques to 32 electrodes and more. Only ten years ago S. Ueno published on "Topographic Computer Display of Abnormal EEG Activities in Patients with CNS Diseases." We may consider that EEG cartography started with this publication, using all the resources of computerized imaging techniques. This was followed in 1979 by F.M. Doffy's first articles on brain electrical EEG mapping (BEAM) and in 1982 by M.S. Buchsbaum and R. Coppola article describing "A New System for Gray-level Surface Distribution Maps of Electrical Activity". In the same year, M.S. Buchsbaum published the first article on "Topographic Cortical. Mapping of EEG Sleep Stages During Day-time Naps in Normal Subjects." This was followed by a growing research interest on EEG cartography in psychiatry, neurology, psychophysiology and pharmaco-EEG.

Presently, with the exception of the M.S. Buchsbaum article, sleep studies have not been conducted with this new, noninvasive, functional, electrophysiological brain imaging method. This is why we have been interested in it and have applied EEG cartography to the first recording of a night under sleep in laboratory conditions.

Protocole

We recorded one night of sleep under sleep laboratory conditions. Sixteen EEC silver electrodes were glued with collodion to the scalp and continuously recorded over seven hours of sleep (REEGA 16, Alvar). The chosen montage was bilateral over the scalp (over the right hemisphere: Fp2, F4, F8, C4, T4, P4, T6, 02; over the left hemisphere: Fp1 F3, F7, C3, T3, P3, T5, 01) according to the 10/20 system of electrode positioning. We have chosen to use a common reference electrode instead of a monopolar linked ears reference electrode (Walter, Etevenon, Pidoux, Tortrat, & Guillou, 1984). A second polygraph (Minihuit Alvar) recorded the EOGs, the EMG of the chin muscles, the respiration, the EKG and the movements of the bed. The 16 EEGs were submitted online to spectral EEG analysis for periods of 6 seconds, 30 seconds or one minute. Spectral

data were recorded on floppy discs, allowing later editions of EEG maps (Cartovar 2000, Alvar Electronics) for the raw EEG amplitude values; and three broad frequency band amplitude values (0-8c 8-13, 13-30 Hz). Spectral values were also fed into HP minicomputers (HP 1000 211.01 F) for further averag-ing and statistical comparisons.

The subject was a normal woman of 55 years with a university background, presenting a high alpha amplitude with eyes closed. She was very well accus-tomed to EEG laboratory conditions and kept a dream diary as she was a good dream recaller. She was awakened three times; at the end of the first three sleep cycles and was asked for dream recall following drowsy sleep (stage 1) or stage REM (paradoxical sleep). Continuous recording of EEG brain waves provided 500 EEG maps during the night. These maps were topographically specific to each stage of sleep.

An image by image 16 mm camera was placed in front of the micro-computer visual display console. A selec-tion of these EEG maps was filmed and presented visually at different speeds (cartooning of twenty seconds or two minutes for each sleep cycle), display-ing EEG changes over the scalp and showing the dynamic features of stages of sleep during the night. Typical EEG maps of drowsy sleep and REM phases were similar to EEG maps taken during arousal states (eyes opened or eyes closed).

A movie (16mm, in colour, 12 minutes) was co-produced by CNRS Audiovisual and SPECIA. The first draft version was shown to the French EEG Society at Tours (June 11th, 1985) during a meeting on sleep, to the ASD meeting in Charlottesville, Virginia in late June of 1985 and to research seminars, in July and August of 1985, at the Brain Research Institute, UCLA, Los Angeles, and at the Dept. of Psychiatry, UCSF, San Francisco. Presently this movie is completed with additional results, with the co-production of Institute National Audiovisual.

Results

A scientific movie has been made of the first results obtained in this EEG cartography study of a night of sleep. It is impossible in this short summary to present the dynamic and pictural aspects of this movie. The electrical activity of the brain was changing every six seconds during the entire night. A drastic selection of EEG maps has been made, choosing 100 maps from over 500 recorded EEG maps. Furthermore, three frequency bands (delta + theta, alpha, beta) have been studied apart from the total raw EEG mapping activity (0 30Hz). This first study of a night of sleep required the edition of more than 2000 EEG maps: raw EEG and three broad frequency bands for absolute amplitude values computed over 16 EEG channels located on the scalp. Further averaging and statistical analyses were computed between EEC maps, according to each well defined stage of sleep based on Rechtschaffen and Kales sleep scoring manual.

In the first two tables, we will present normative data from our statistical results.

The first table shows that there is a linear trend of increased EEG amplitude in this sequence: the arousal, eyes open; REM periods; stage 1 of drowsiness; quiet arousal, eyes closed; stage II of light sleep and stages III and IV of slow wave sleep activities. This is in favor of Johnson's hypothesis separating REM stages (II and III - IV).

Table 1

Maximal Mean Amplitude of EEG Maps for Stages of Wake-Sleep Cycle

Stage	n	Mean Amplitude ± 1 S.D. (microvolts, 0-30 Hz)
Arousal, eyes open	7	22.86 ± 1.82
Arousal, eyes closed	27	120.00 ± 6.74
I	15	47.80 ± 5.70
II	11	135.82 ± 15.79
III - IV	19	203.00 ± 14.67
REM	37	43.92 ± 3.43

The second table presents mean amplitudes in microvolts of the six stages of vigilance and sleep as a function of the three basic frequency bands (slow waves activities delta + theta, alpha, beta). Based on these results REM and non-REM stages are well described by *two* lines drawn in a three dimensional display (with the three frequency band amplitude values having X, Y, and Z axes). One segment of the line starts with the stage of arousal, eyes open; REM; stage I and ends at the location (in the X, Y, Z space) of the spot for quiet arousal, eyes closed. The second line starts at this last point and follows the points of stage II, up to the stage III and IV loca-tion in the 3D graph.

The third table gives the correlation coefficients computed between two sets of maximal mean amplitude values for EEG maps obtained for each stage of vigilance (eyes open, eyes closed) or sleep cycle (I, II, III-IV, REM). We may observe from this table that the raw EEG amplitude values are significantly correlated with the slow activities (delta + theta) for each stage (except eyes open, but this is probably because of a small sample of EEG maps). The raw EEG was also correlated with alpha and beta amplitude

values for each stage: except for the first stage, “eyes open”, with beta activity, and for stage II, but according to the second table the amplitude values of these frequency bands are much smaller than delta + theta slow waves amplitude values. From these first results it appears that EEG maps based on; raw EEG amplitude values are sufficient to describe each stage of’ the vigilance and sleep cycle. However, correlations between frequency bands, amplitude values are smaller except for stage I and stages III — IV.

Table 2

Maximal Mean Amplitudes by Frequency Bands of EEG Maps for Stages of Wake Sleep Cycle as a Function of the Three Basic Frequency Bands

Stage	n	(Delta + Theta) (0-8Hz)	Alpha (8-13Hz)	Beta (13-30Hz)
Arousal eyes open	7	12.86 ± 0.88	11.71 ± 1.74	2.86 ± 0.40
Arousal eyes closed	14	34.64 ± 3.65	90.43 ± 6.25	10.64 ± 0.81
I	18	36.28 ± 5.02	12.44 ± 1.64	10.16 ± 1.01
II	7	110.14 ± 18.33	11.57 ± 1.88	9.14 ± 1.14
III - IV	10	182.30 ± 22.22	7.60 ± 1.11	7.10 ± 1.05
REM	8	30.63 ± 3.69	9.75 ± 0.94	8.88 ± 2.07

Table 3

Correlation Coeficients for Each Stage
Between Two Spectral Amplitude Parameters

Stages	n	EEG & Delta Theta	EEG & Alpha	EEG & Beta	Delta & Alpha	Alpha & Beta	Delta & Beta
Eyes open	7	.38	.83*	.25	0.01	0.46	0.01
Eyes Closed	26	.49*	.92*	.43*	0.26	0.34	0.49*
I	14	.98*	.76*	.76*	0.64*	0.66*	0.73*
II	11	.99*	.11	.30	0.0004	0.62*	0.41
III - IV	19	.99*	.55*	.75*	0.53*	0.76*	0.73*
REM	29	.95*	.47*	.52*	0.28	0.29	0.37*

*Correlation coefficient statistically significant at $p \leq 0.05$.

Conclusions

EEG cartography of sleep fluctuations is a new tool for studying functional cortical activities projected over the scalp Moreover, we have tried to correlate dream content obtained after the awakening of the subject and the EEG maps prior to the awakening. Brain activation can be seen as a decrease in amplitude and an increase in frequency over a specific EEG electrode location. At the end of the first sleep cycle, our subject was awakened after six minutes of stage I. She reported an abstract fuzzy dream very quickly forgotten. The stage I EEG map (with a maxi-mal amplitude of 39 uV over left parietal and right frontal areas and minimal values over left temporal central area) was nevertheless quite similar to an EEG map obtained in active arousal, eyes open. In this case, we think that the hypnagogic imagery produced an “inner arousal state” but with a possible dissociation with recall and verbal expression of the dream content.

After the second sleep cycle, the subject was awakened following 13 minutes of continuous REM stage sleep. She reported a visual dream. She was carrying luggage and

taking a train. The EEG map of the related REM state presented a maximal amplitude value of 62 uV over left occipital area together with minimal values (activated areas) over left temporal and right parietal. We may suppose that the activated brain areas over the auditory cortex and left somato-motor area may be related to the ambient noise of the train station and the carrying of the luggage. The activated right visual area could be related to the visual activation in the dream.

After the third sleep cycle, following 13 minutes of REM stage, the subject was awakened for the third time. She reported a visual and auditory dream where she was calling the mother of a dear friend. She saw the telephone on her desk and herself dialing and calling. She used her right hand for handling the phone and she recalled the lively conversation. The REM EEG map prior to the dream recall was very much like an EEG map taken during active arousal, eyes open. The maximal values (relaxed EEG areas) were of 38 uV over left parietal and occipital areas. The minimal values were a large diagonal strip between left temporal and right parietal with a minimum of 4 uV over the left central area (which may be considered as a contralateral somato-motor projection of the right hand).

The last findings are only preliminary results and they need further confirmations with different sub-jects, different EEG montage, different reference electrodes. Despite these points, we think that EEG cartography applied to the study of vigilance states, sleep stages and REM studies related to dream contents, presents a major methodological tool for future research. For further details of this work see Etevenon et al., (1985a; 1985b) and Etevenon (1985).

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