Investigation of Brain Potentials in Sleeping Humans Exposed to the Electromagnetic Field of Mobile Phones.

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ABSTRACT: An investigation was made of 8-hour EEG tracings of sleeping humans exposed to the electromagnetic field of a GSM-standard mobile phone. To analyze the EEG-patterns, manual scoring, nonlinear dynamics, and spectral analysis were employed. It was found that, when human beings were exposed to the electromagnetic field of a cellular phone, their cerebral cortex biopotentials revealed an increase in the α-range power density as compared to the placebo experiment. It was also found that the dimension of EEG correlation dynamics and the relation of sleep stages changed under the influence of the electromagnetic field of a mobile phone.

LITERATURE REVIEW

Normal sleep is made up of cyclic variations in the functional state of the brain. The most salient and invariable feature of sleep consists in that the brain shows a decrease in the cerebral cortex activity on the scale "sleep–wakefulness". The functional state of the brain is usually studied by means of an electroencephalogram (EEG). An analysis of electroencephalograms made earlier demonstrated that sleep is an inhomogeneous process. It has a complex structure and a certain sequence of alternating patterns. There are many classifications of sleep due to numerous approaches to the description of EEG patterns.

One of the first classifications made it possible to analyze EEG patterns in sleeping subjects [1]. However, the application of this classification can only show how deep is the subject's sleep. In other words, this classification is capable of revealing only two stages of sleep, such as drowsiness and deep (slow-wave) sleep. The discovery of the rapid-eye-movement (REM) stage of sleep allowed the development of a new classification [2]. According to this classification, sleep was divided into orthodox sleep, which does not involve rapid eye movements, and into paradoxical, or REM, sleep.

The most complete classification of polysomnographic sleep records is given in [3]. It uses electroencephalograms, electromyograms, electrooculograms, and some other techniques. This approach made it possible to recognize five alternating stages of sleep with certain EEG correlates for every stage.

The *first stage* is marked by a relatively low amplitude and mixed frequencies with a pronounced activity at 2 to 7 Hz. The duration of this stage is relatively short and it ranges from 1 to 7 min. This stage occurs mostly when a person starts to fall asleep or between other stages of sleep. The *second stage* is

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recognized by a relatively low amplitude, "sleep spindles", and *K*-complexes arising either due to responses to unexpected stimuli or in the absence of any differentiable stimuli. This stage constitutes approximately a half of the total sleeping time. The *third stage* is characterized by slow high-amplitude waves, which account for 20 to 50% of the whole analyzed period. The *fourth stage* shows high-amplitude waves with a frequency of 2 Hz. These waves make up more than 50% of the whole analyzed period. The *fifth stage* (or *REM-stage*) is distinguished by a relatively low amplitude and by mixed EEG frequencies periodically interrupted by episodes of REM sleep.

Presently, researchers make use of all the enumerated classifications of sleep stages depending on the solved problem.

In healthy adults, night sleep is made up of 4 to 6 sleep cycles that include all five stages. Each cycle begins with a period of slow-wave sleep. On the average, each cycle lasts for 90 min. However, the first cycle lasts longer than the final ones.

However, night sleep of healthy people can be affected by many kinds of things in the environment. For example, sleep is dependent on personality and it was found to be different in morning types and evening types [4–7]. Apart from that, sleep depends on the time when a person goes to bed and on the time during which he or she stayed awake before going to bed [8, 9]. In addition, sleep depends on the surroundings [10], age [11], subject's geomagnetic orientation [12, 13], and other conditions.

In view of a constantly aggravating electromagnetic pollution of the environment, it seems essential to study the effect of various electromagnetic devices and equipment on the activity of the central nervous system of human beings [14], for example, during their sleep [15].

METHODS

Our investigation was conducted on 20 volunteers (20 men aged from 20 to 28). We made two runs of experiments, in which the volunteers were exposed to simulated (sham) and actual electromagnetic fields of a mobile phone in random order. Two-channel EEG tracings were recorded during an 8-hour laboratory sleep. The EEG tracings were recorded in the C_Z and P_Z leads, with the reference electrode being placed in the F_Z lead.

As soon as electroencephalograms were recorded, sleep stages were scored manually and then their duration and alternation were analyzed. After that, nonlinear dynamics methods were employed to calculate correlation dimension and then FFT-based spectral analysis was used. We left out of account periods affected by muscular motion or winking artifacts. For normal EEG periods, we calculated the absolute spectral power in the δ-, θ-, α-, and β-ranges and the correlation dimension D_2 for each lead. The secondary statistical treatment was carried out with the aid of variance analysis (ANOVA).

RESULTS

The spectral analysis of EEG patterns obtained from sleeping humans demonstrated that reliable variations in the spectral power indices were observed only in the α-range for the P_Z lead (Figure 1, Table 1). An increased spectral power in the α-range can be explained by the fact that this range is most reactive to the influence of electromagnetic fields [16, 17]. A similar tendency of changes was also observed in the δ- and θ-ranges. However, the β-range did not exhibit significant variations or tendencies. It was also found that volunteers exposed to the actual electromagnetic field of a mobile phone showed a significant decrease ($p < 0.05$) in the two-channel correlation dimension D_2 during an 8-hour sleep as compared to the placebo experiment with a simulated electromagnetic field (Figure 2).

The mean values of correlation dimension indices D_2 for EEG tracings recorded during an 8-hour sleep from the C_z and P_z leads are presented in Figure 3 and in Table 2. Although the decrease in D_2 was significant ($p < 0.05$) for both leads, it was more pronounced for the C_z lead.

Table 1. *Mean values of the spectral power indices in the α-range for simulated and actual electromagnetic fields of a mobile phone*

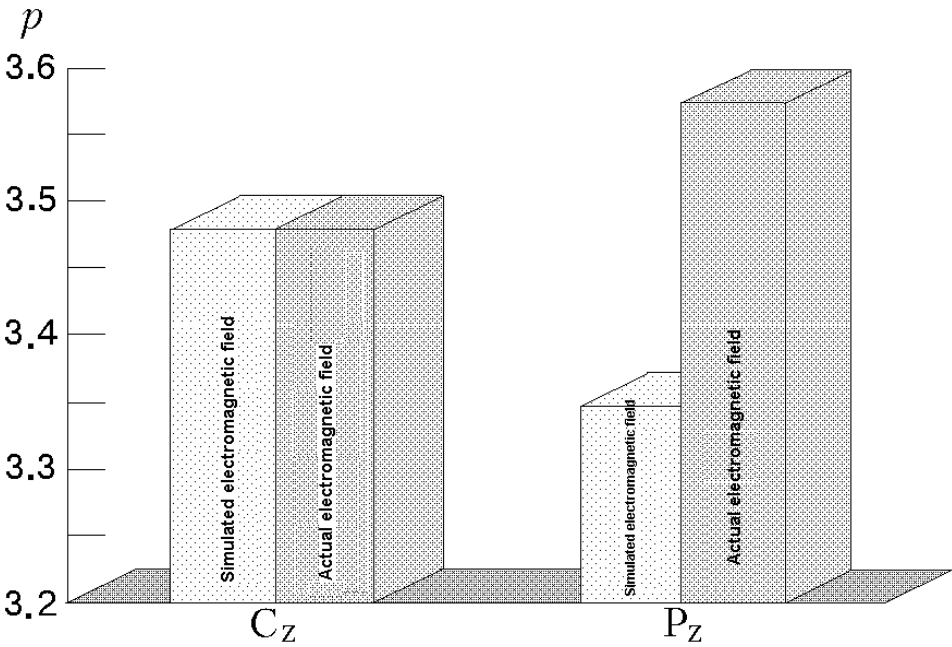| Lead	Simulated Electromagnetic Field	Actual Electromagnetic Field
C_z	3.47840	3.4813
P_z	3.346288	3.574357

FIGURE 1. Mean values of the EEG spectral power density in the α-range obtained from the C_z and P_z leads during an 8-hour sleep for simulated and actual electromagnetic fields of a mobile phone ($p_{Pz} < 0.05$).
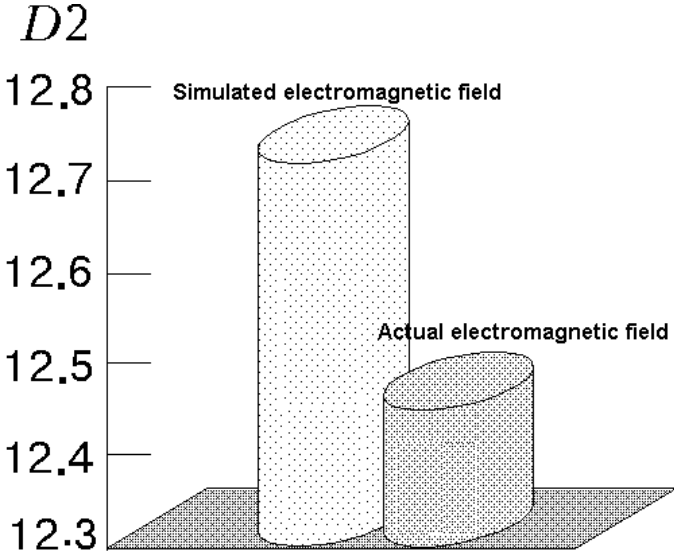

FIGURE 2. Mean values of the two-channel correlation dimension D_2 during an 8-hour sleep.
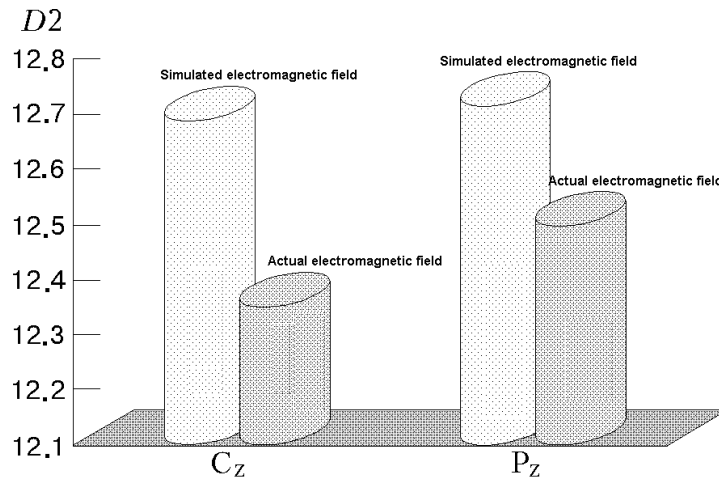
FIGURE 3. Mean values of the correlation dimension indices D_2 obtained from the C_z and P_z leads during an 8-hour sleep.

Table 2. *Mean values of the correlation dimension indices D_2 for simulated and actual electromagnetic fields of a mobile phone*

Lead	Simulated Electromagnetic Field	Actual Electromagnetic Field
C_z	12.70191	12.36518
P_z	12.73272	12.51446

The dynamics of the correlation dimension indices D_2 during an 8-hour sleep for simulated and actual electromagnetic fields of a mobile phone is shown in Figure 4. Similar patterns were observed for every lead.

Manual scoring demonstrated that, when volunteers were exposed to simulated and actual electromagnetic fields of a mobile phone, they exhibited insignificant differences in sleep stages. However, one can see that the percentage of slow-wave sleep during the whole 8-hour sleep revealed a tendency to decrease in volunteers exposed to the actual electromagnetic field (Figure 5, Table 3).

Table 3. *Percentage of the slow-wave sleep for simulated and actual electromagnetic fields of a mobile phone*

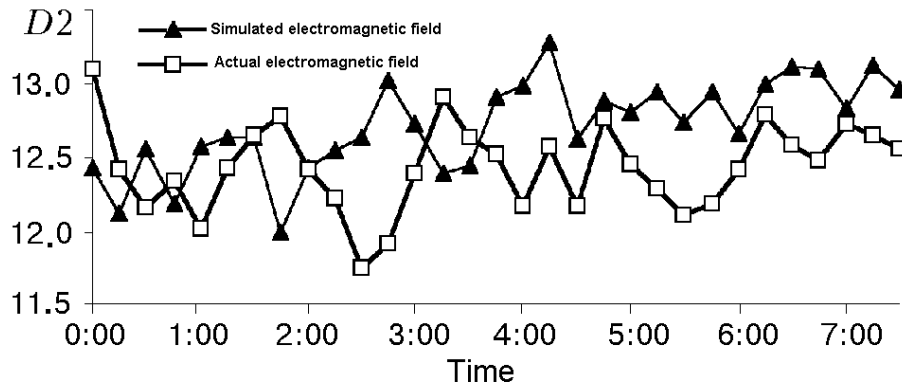| Lead	Simulated Electromagnetic Field	Actual Electromagnetic Field
C_z	32.5754	29.5682
P_z	32.0531	29.8533

FIGURE 4. Dynamics of the mean correlation dimension indices D_2 obtained from the C_Z and P_Z leads during an 8-hour sleep for simulated and actual electromagnetic fields of a mobile phone ($p < 0.05$).

DISCUSSION

It is known that the structure of night sleep includes deep synchronized slow-wave sleep (SSWS), which takes a large part of the first half of a sleep cycle. SSWS percentage then decreases and EEG tracings reveal desynchronization processes. These processes are typical of nonsynchronized slow-wave sleep (NSSWS), which includes the first, the second, and the fifth (or REM) stages [3].

It is also known [18] that EEG correlation dimension indices D_2 of SSWS are significantly lower than those of NSSWS. This is associated with the fact that processes occurring in the brain at the third and fourth stages take a simplified course. During the second half of night sleep, NSSWS becomes dominating and the cerebral cortex's bioelectrical processes get more complicated. This gives rise to increased values of D_2. It is this dynamics of D_2 that was seen during sleep in human beings exposed to a simulated electromagnetic field (Figure 4).
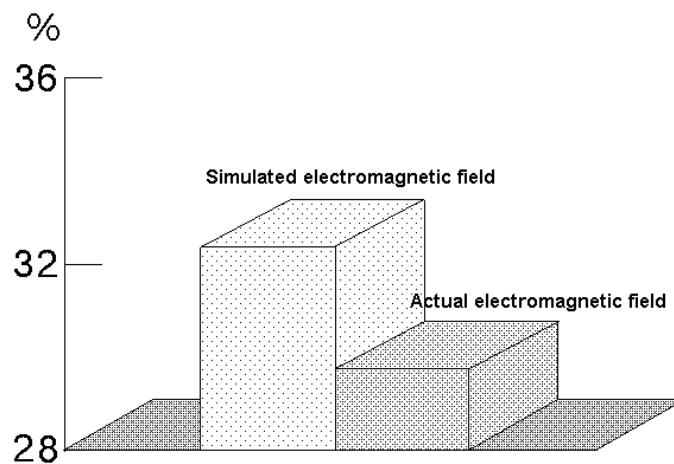

FIGURE 5. Percentage of the slow-wave sleep (the third and the fourth stages) with respect to the whole 8-hour sleep structure for simulated and actual electromagnetic fields of a mobile phone.

However, when volunteers were exposed to the actual electromagnetic field of a mobile phone, they exhibited a different EEG pattern. Although during the first half of their sleep the dynamics of D_2 was virtually identical to that of the

control group, it did not show the expected increase in D_2 during the second half of their sleep. Moreover, it remained invariable to the end of our experiment. Thus, the dynamics of D_2 provided evidence for a changed sleep structure, which was related to the NSSWS depression. Similar results were reported in [15], in which healthy people were exposed to the electromagnetic field of a cellular phone and they also revealed a suppressed REM-stage (which is one of NSSWS stages). Apart from that, one can see from Figure 5 that the slow-wave sleep cycle (the third and fourth stages) revealed a tendency to decrease under the influence of the actual electromagnetic field, although this effect was not significant.

Thus, taking into account the results obtained in [18] and results presented in Figures 4 and 5, one can postulate that a prolonged exposure to the electromagnetic field of a mobile phone brings about a pronounced sleep structure transformation. In this case, sleep is largely made up of the first and second sleep stages, which involve no dreaming. Bearing in mind that the first stage is rather short and that it mainly accompanies the REM-stage, one can conclude that, when human beings were exposed to the actual electromagnetic field of a mobile phone, a great part of their sleep consisted of the second sleep stage, which is typical of aged people [3].

It is known that the fundamental biological role of sleep in live organisms is directed to providing adaptive regulation. On the one hand, sleep reduces functional loads on various bodily systems, such as the nervous system, the cardiovascular system, and the muscular system, with this reduction taking place during the third and the fourth sleep stages. On the other hand, the adaptive role of dreaming, which occurs during the REM-stage, is also of great importance because dreaming helps people to process stored information and to reduce psychological tension.

Hence, the electromagnetic field of a mobile phone affects the sleep structure and reduces slow-wave and REM-stage sleep percentage, which is able to decrease the adaptive reactions of human beings and to impair their state of health as a result of this.

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