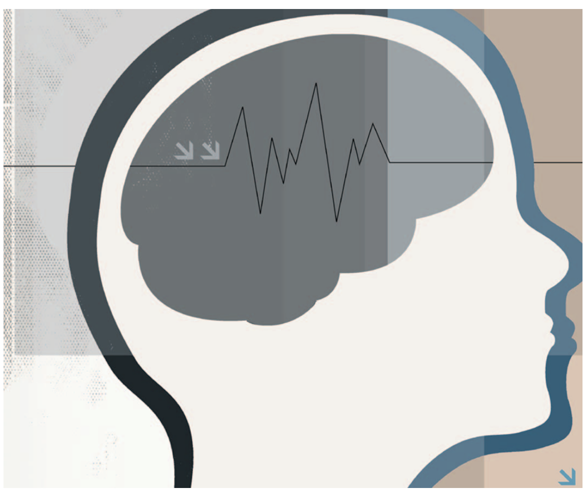
Health Effects

Human EEG and Microwave Radiation from Cell Phones

■ James C. Lin



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The neurological system is an essential integrator of biological functions in all living organisms, playing an essential role in the vital processes of highly developed animals and humans. The neurological system adapts and regulates the whole body in relation to changes in the external environment, to maintain homeostasis within physiological limits. A disturbance in the normal function of the neurological system could also result in changes on other body systems.

James C. Lin is with the University of Illinois, 851 S. Morgan Street, M/C 154, Chicago, IL 60607-7053 USA, +1 312 413 1052. lin@uic.edu.

The neurological system is divided into the central nervous system (CNS), which includes the brain and spinal cord; the peripheral nervous system (PNS); and the autonomic nervous system (ANS), which includes nerve fibers that innervate smooth and heart muscles, and the glands of the body. Anatomically, the brain has three main parts.

1) The brain stem, or medulla, is responsible for the unconscious and involuntary control of important reflex functions such as heartbeat and respiration. The medulla also relays nerve impulses to other parts of the brain.
2) The cerebellum is the center of coordination and balance.
3) The cerebrum is the center for sensation, consciousness, and all voluntary actions.

The CNS is in communication with the PNS and is the integrator and processor into which information concerning the ambient environment, the surface of the body, and the environment inside the body is constantly being fed from sensors and receptors located in all parts of the body. This information may be processed and stored in the memory, or it may be processed and acted upon by sending appropriate impulses out via the motor nerve fibers. A very large part of this constant activity takes place at levels below consciousness.

The neurological system is probably the most vulnerable of all the body systems to adverse assaults. It is the first system to go when the oxygen supply is discontinued. Moreover, the cerebral cortex is the part of the brain that is most vulnerable. Thus, many functions associated with the cerebral cortex are among the first to be impaired. This vulnerability of the nervous system and the cerebral cortex accounts for the observation that a very low level of intoxication may not show effects in other organs or bodily systems but may show effects in the activity of the nervous system.

Although sleep may seem like a mundane event, it actually consists of several fascinating stages, characterized by brain waves or electroencephalographic (EEG) changes that cycle throughout sleep [1].

There are two distinct states of EEG activities during sleep: the nonrapid-eye movement (NREM) state, commonly known as slow wave sleep, and the rapid-eye movement (REM) state. These two states last about 90 min per cycle, which is repeated approximately five times a night, and each cycle includes four stages of NREM and REM sleep. The predominant EEG characteristics are classified into several approximate frequency bands: slow or delta waves, for frequencies less than 4 Hz; theta wave, for frequencies between 5-8 Hz; alpha waves, for 9-12 Hz; and beta waves, for low amplitude but higher frequencies (above 13 Hz). Alpha waves occur during the transition period between sleep and alertness, and beta waves occur when the brain is quite active in the REM stage. Delta and theta waves appear during the NREM stage.

The occurrence of beta waves during REM stages is thought to be associated with information processing in the brain, especially concerning memory functions and learning processes. Also, major depressions are known to be associated with increased REM stages of sleep. The presence of slow delta and theta waves in the EEG of awake adults are symptomatic of pathology. Neural pathology typically enhances slow wave activity and attenuates fast waves (alpha and beta frequency bands). For example, a localized brain tumor would be expected to increase delta- and theta-wave activity, and to decrease alpha or beta waves.

The effects of exposure to microwave radiation from cellular mobile telephones on human brain wave potentials or electroencephalograms have been the subjects of several investigations. The topic is of interest because of the implications of induced changes in the functional state or the well being of the brain. In these studies, EEG activities in awake subjects and during various stages of sleep were examined by polysomnography in human volunteers.

All-night polysomnographs of healthy male subjects were recorded, both with and without exposure to global system for mobile communications (GSM) signals (900 MHz, pulse repetition frequency of 2, 8, and 217 Hz, pulsewidth 577 μm, and 0.5 W/m^2). A shortening of sleep onset latency, which was interpreted as a hypnotic effect, and a REM suppressive effect with reduction of duration and percentage of REM sleep were observed under the pulse-field-exposure conditions [2]. Moreover, spectral analysis revealed an increased spectral power density of the EEG signal during REM stages in the alpha-frequency band. However, since then, a series of reports from the same laboratory gave conflicting results on the influence of microwave radiation from mobile telephones on human sleep EEG patterns at power densities that ranged from 0.5 to 50 W/m^2. Specifically, subsequent studies that involved 20–24 subjects failed to confirm these findings, although there was a trend toward an REM suppressive effect. [3]–[5].

In another laboratory, healthy young subjects were exposed all night to mobile telephone fields with base-station-like GSM signals (900 MHz, 2, 8, 217 and associated harmonics, and bursts related components at 1,736 Hz and 50 kHz) at a spatial peak specific absorption rate (SAR) of 1 W/kg averaged over 10 g, in alternating intervals of a 15-min on–15-min-off schedule during sleep [6]. It was found that the spectral power of the EEG in NREM sleep was increased. The maximum rise occurred in the alpha frequency (10–11 and 13.5–14 Hz) bands during the initial part of sleep. Moreover, compared to a control night with sham exposure, the amount of waking after a sleep onset was reduced from 18 to 12 min. The results suggested that pulse-modulated microwaves from mobile phones may promote sleep and modify the sleep EEG.

A similar change was observed in a subsequent study from this laboratory, where the same cellular-phone fields were applied for 30 min during the waking period preceding sleep [7]. The maximum rise in the spectral power of the EEG during NREM sleep occurred in essentially the same alpha (9.75–11.25 and 12.5–13.25 Hz) frequency bands during the first stage of sleep. Since these changes correspond to those obtained in a previous study where the GSM field was intermittently applied during sleep, the present results showed that exposure during waking modify the EEG during subsequent sleep. These EEG studies involved a double-blind design, and the order of conditions was balanced.

A more recent report from this laboratory provided further evidence for the effect on sleep EEG from exposure to microwave fields with GSM-phone-like modulations [8]. A group of 16 young male human subjects was exposed to 30 min of handset-like GSM signals at the common carrier frequency of 900 MHz and an SAR of 1 W/kg. Note that, while the modulation schemes for base-station and handset type signals are the same, the spectral power contents of the frequency components are considerably higher in the handset-type signal. In addition, a continuous-wave (CW) exposure regime was used in this study.

A sleep onset latency of 13-15 minutes was found not significantly different under sham and exposed conditions. There was an increased spectral power density in the alpha-frequency band of the EEG signal prior to a sleep onset compared to sham exposure, but the effect was not evident under CW exposure. Furthermore, the exposure with GSM modulation was seen to increase the spectral power in the 12.25-13.5 Hz range of the subject's NREM sleep EEG. This increase is characteristic of the so-called, "sleep spindles," in which peaks of oscillatory EEG events become higher and higher, in the shape of spindles. A detailed examination of the time course revealed a pronounced difference between exposure to GSM- or CW-modulated fields.

Aside from the difference in the effect of GSM and CW modulations, this study showed a long-lasting effect on the EEG in contrast to their two earlier studies. A possible, albeit untested, explanation is that the difference in the pulse architecture between handset and base-station type signals. The spectral power at 2 and 8 Hz for the handset type signal was higher. Also, while the average SAR of 1 W/kg was the same for both, the peak SAR for the handset type signal was four times higher than for the base-station type.

In another laboratory, the EEG activity was recorded and analyzed in awake subjects (men and women, 28–57 years old), who were exposed to five different mobile telephones (analog and digital models), operating at a carrier frequency of 900 or 1,800 MHz for 20 min [9]. The recording was made for each subject under the closed-eyes situation during six 30-min experiments, including one sham exposure. No change was observed during exposure in any frequency bands, except for one of the telephones. In that case, a statistically significant change in the absolute power at the delta-frequency band of the EEG recording was seen. Since the presence of delta brain waves (< 4 Hz) in the EEG of awake adults are symptomatic of neural pathology, this finding could be of potential concern. However, no difference occurred in the relative power of the delta-frequency band between sham and exposed periods. The authors concluded that "the observed difference in one parameter was probably caused by statistical chance."

It should be mentioned that, in a similar study, EEG recordings were made during a 60-min session: 15 min of background, 15 min of field-exposure or sham-exposure, and 30 min after the exposure [10]. A significant increase of the global correlation dimension—an indicator of functional state changes in the brain was noticed—during the exposure and after exposure period, under the eyes-closed condition. (The global-correlation dimension is a single, value-quantitative estimate of the complexity of brain state that describes the ensemble characteristics of all recorded channels, independent of amplitude and frequency measures.)

It appears that conventional polysomnography techniques were applied in all the studies mentioned. In particular, a large number of small, metallic electrodes typically are placed upon a subject's scalp, with electrically conducting paste or a glue-like substance to hold them in place. Low voltage signals (< 500 μV) are amplified by the electronics in the EEG recording system. The resulting polygraphic display is then read by unaided visual inspection, followed by spectral analysis.

The use of metallic electrodes raises some questions concerning cellular-phone-radiation-induced interference and field concentration on and in the vicinity of metallic electrodes. These electrodes are known to perturb the microwave field and to produce electrophysiological recording artifacts [11], [12]. The observation that pulse modulation was critical for cellular-phone-radiation-induced enhancement of EEG power in specific frequency ranges during waking and sleep, and the fact that the peak SAR delivered by pulse modulations was four times higher than CW modulations, seem to support such a speculation. However, since EEG recording was made post cell-phone exposure in [8], this potential deficiency in methodology may or may not be a factor in the interpretation of the reported results. Nevertheless, the potential for field concentration on and in the vicinity of metallic electrodes should be a cause for concern during exposure.

Indeed, the most recent publication from this group reported studies conducted to assess and measures taken to minimize potential electrodes-related artifacts [13]. The variations in local SAR distributions, with and without the presence of electrodes, were of the order of 40%. They also reported measuring a 35% higher peak SAR (spatially averaged over 1 g of tissue) from currents induced on electrode wires.

In summary, these results imply that microwave radiation from mobile telephones could modify certain brain electrical activity under both awake and sleep conditions. However, the results were inconsistent. In particular, the results of the two series of studies from two different laboratories were most intriguing. A series of reports from one laboratory gave conflicting results on the influence of microwave radiation from mobile telephones on human EEG activity. In contrast, results from another laboratory not only extended its earlier findings that microwave radiation from mobile telephones can affect human EEG activity, but also suggested that pulse-modulated microwaves from mobile phones may promote sleep and modify human brain electrical activity (but not the CW modulation). While the investigators emphasized that the observed effects were "subtle," they had indicated that the observation might provide "important new insights into the mechanism" of the influence. Furthermore, it was suggested that future studies should explore "its potential as a noninvasive method of influencing the brain for experimental, diagnostic, and therapeutic purposes."

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