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Mobile phones and sleep – A review

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The increasing use of mobile phones has raised concerns regarding the potential health effects of exposure to the radiofrequency electromagnetic fields. An increasing amount research related to mobile phone use has focussed on the possible effects of mobile phone exposure on human brain activity and function. In particular, the use of sleep research has become a more widely used technique for assessing the possible effects of mobile phones on human health and wellbeing especially in the investigation of potential changes in sleep architecture resulting from mobile phone use. Acute exposure to a mobile phone prior to sleep significantly enhances electroencephalogram spectral power in the sleep spindle frequency range. This mobile phone-induced enhancement in spectral power is largely transitory and does not linger throughout the night. Furthermore, a reduction in rapid eye movement sleep latency following mobile phone exposure was also found, although interestingly, neither this change in rapid eye movement sleep latency or the enhancement in spectral power following mobile phone exposure, led to changes in the overall quality of sleep. In conclusion, a short exposure to the radiofrequency electromagnetic fields emitted by a mobile phone handset immediately prior to sleep is sufficient to induce changes in brain activity in the initial part of sleep. The consequences or functional significance of this effect are currently unknown and it would be premature to draw conclusions about possible health consequences.

Key words: mobile phones, health effects, brain activity and function, sleep architecture, electroencephalogram.

Introduction

The use of mobile phones is continually increasing throughout the world, with recent figures showing that there are currently more than 2 billion mobile phone users worldwide. However, despite the recognised benefits of the introduction and widespread use of mobile phone technologies, concerns regarding the potential health effects of exposure to the radiofrequency electromagnetic fields emitted by mobile phone handsets have similarly increased, leading to an increase in demand for scientific research to investigate the possibility of health effects related to the use of mobile phones. An increasing amount of radiofrequency bioeffects research related to mobile phone use has focussed on the possible effects of mobile phone exposure on human brain activity and function, particularly as the absorption of energy in the head and brain region is much higher than in other body regions, which is a direct result from the close proximity of the mobile phone to the head when in normal use. In particular, the use of sleep research has become a more widely used technique for assessing the possible effects of mobile phones on human health and wellbeing, and is particularly useful for providing important information in the establishment of possible radiofrequency bioeffects, especially in the investigation of potential changes in sleep architecture resulting from mobile phone use.

Effect on regional cerebral blood flow

Usage of mobile phones is rapidly increasing, but there is limited data on the possible effects of electromagnetic field (EMF) exposure on brain physiology. Huber et al [7] investigated the effect of EMF vs. sham control exposure on waking regional cerebral blood flow (rCBF) in humans. Positron emission tomography (PET) scans were taken after unilateral head exposure to 30-min pulse-modulated 900 MHz electromagnetic field (pm-EMF). Pulse-modulated EMF exposure increased relative rCBF in the dorsolateral prefrontal cortex ipsilateral to exposure. The present results showed for the first time that pm-EMF alters waking rCBF. Pulse-modulated EMF exposure may provide a new, non-invasive method for modifying brain function for experimental, diagnostic and therapeutic purposes.

Huber at al [9] investigated the effects of radio frequency electromagnetic fields (RF EMF) similar to those emitted by mobile phones on waking regional cerebral blood flow (rCBF) in 12 healthy young men. Two types of RF EMF exposure were applied: a ‘base-station-like’ and a ‘handset-like’ signal. Positron emission tomography scans were taken after 30 min unilateral head exposure to pulse-modulated 900 MHz RF EMF (10 g tissue-averaged spatial peak-specific absorption rate of 1 W/kg for both conditions) and sham control. They observed an increase in relative rCBF in the dorsolateral prefrontal cortex on the side of exposure. The effect depended on the spectral power in the amplitude modulation of the RF carrier such that only 'handset-like' RF EMF exposure with its stronger lowfrequency components but not the 'base-station-like' RF EMF exposure affected rCBF. This finding supports their previous observation that pulse modulation of RF EMF is necessary to induce changes in the waking and sleep EEG, and substantiates the notion that pulse modulation is crucial for RF EMF-induced alterations in brain physiology.

Mobile phones create a radio-frequency electromagnetic field (EMF) around them when in use, the effects of which on brain physiology in humans are not well known. Aalto et al [1] studied the effects of a commercial mobile phone on regional cerebral blood flow (rCBF) in healthy humans using positron emission tomography (PET) imaging. Positron emission tomography data was acquired using a double-blind, counterbalanced study design with 12 male subjects performing a computer controlled verbal working memory task (letter 1-back). Explorative and objective voxel-based statistical analysis revealed that a mobile phone in operation induces a local decrease in rCBF beneath the antenna in the inferior temporal cortex and an increase more distantly in the prefrontal cortex. Their results provideed the evidence, suggesting that the EMF emitted by a commercial mobile phone affects rCBF in humans. Their results were consistent with the postulation that EMF induces changes in neuronal activity.

Human studies

Borbely et al [2] investigated whether the electromagnetic field (EMF) emitted by digital radiotelephone handsets affects the brain, healthy, young subjects were exposed during an entire night-time sleep episode to an intermittent radiation schedule (900 MHz; maximum specific absorption rate 1 W/kg) consisting of alternating 15-min on 15-min off intervals. Compared with a control night with sham exposure, the amount of waking after sleep onset was reduced from 18 to 12 min. Spectral power of the electroencephalogram in non-rapid eye movement sleep was increased. The maximum rise occurred in the 10-11 Hz and 13.5-14 Hz bands during the initial part of sleep and then subsided. The results demonstrate that pulsed high-frequency EMF in the range of radiotelephones may promote sleep and modify the sleep EEG.

Wagner et al [14] investigated the influence of radiofrequency electromagnetic fields (EMFs) of cellular phone GSM signals on human sleep electroencephalographic (EEG) pattern, all-night polysomnographies of 24 healthy male subjects were recorded, both with and without exposure to a circular polarized EMF (900 MHz, pulsed with a frequency of 217 Hz, pulse width 577 μs, power flux density 0.2 W/m^2). Suppression of rapid eye movement (REM) sleep as well as a sleep-inducing effect under field exposure did not reach statistical significance, so that previous results indicating alterations of these sleep parameters could not be replicated. Spectral power analysis also did not reveal any alterations of the EEG rhythms during EMF exposure. The failure to confirm their previous results might be due to dose-dependent effects of the EMF on the human sleep profile.

Former exploratory investigations of sleep alterations due to global system for mobile communications (GSM) signals have shown a hypnotic and REM-suppressive effect under field exposure. This effect was observed in a first study using a power flux density of 0.5 W/m^2, and the same trend occurred in a second study with a power flux density of 0.2 W/m^2. Wagner et al [15] applied a submaximal power flux density of 50 W/m^2. To investigate putative effects of radio frequency electromagnetic fields (EMFs) of cellular GSM phones on human sleep EEG pattern, all-night polysomnographies of 20 healthy male subjects both with and without exposure to a circularly polarized EMF (900 MHz, pulsed with a frequency of 217 Hz, pulse duration 577 μs) were recorded. The results showed no significant effect of the field application either on conventional sleep parameters or on sleep EEG power spectra.

Huber et al [6] investigated whether the electromagnetic field (EMF) emitted by digital radiotelephone handsets affects brain physiology. Healthy, young male subjects were exposed for 30 min to EMF (900 MHz; spatial peak specific absorption rate 1 W/kg) during the waking period preceding sleep. Compared with the control condition with sham exposure, spectral power of the EEG in non-rapid eye movement sleep was increased. The maximum rise occurred in the 9.75 ± 11.25 Hz and 12.5 ± 13.25 Hz band during the initial part of sleep. These changes correspond to those obtained in a previous study where EMF was intermittently applied during sleep. Unilateral exposure induced no hemispheric asymmetry of EEG power. The present results demonstrate that exposure during waking modies® the EEG during subsequent sleep. Thus the changes of brain function induced by pulsed high-frequency EMF outlast the exposure period.

Hamblin and Wood [4] compared the findings of the main studies that have examined the effects of GSM mobile phone radiofrequency emissions on human brain activity and sleep variables. Fourteen published studies reporting on human brain electrical activity measurements during and/or after such radiofrequency emissions were identified and compared. Although, in general, outcomes have been inconsistent and comparison between individual studies is difficult, enhanced electroencephalogram alpha-band power has been noted in several of the studies, a phenomenon also observed in some animal studies. Performance decrements observed in some recent extremely low frequency studies are consistent with enhanced alpha-band power, highlighting the possible role of extremely low frequency fields associated with battery current in mobile phone handsets. However, more complex cognitive tasks appear to show improved performance in relation to mobile phone exposure. Significant cognitive effects have been reported using both modulated and unmodulated radiofrequency carriers. The possibility of putative effects being due to extremely low frequency demodulation is therefore unlikely. There are no obvious associations between the site of exposure and regions of the brain from which effects are reported or implied. Lastly, radiofrequency effects have been reported to occur both during exposure and up to 1 h or so after cessation of exposure.

Usage of mobile phones is rapidly increasing, but there is limited data on the possible effects of electromagnetic field (EMF) exposure on brain physiology. Huber et al [7] investigated the effect of EMF vs. sham control exposure on waking and sleep electroencephalogram (EEG) in humans. Night-time sleep was polysomnographically recorded after EMF exposure. PM-EMF exposure enhanced EEG power in the alpha frequency range prior to sleep onset and in the spindle frequency range during stage 2 sleep. Exposure to EMF without pulse modulation did not enhance power in the waking or sleep EEG. The present results showed for the first time that pulse modulation of EMF is necessary to induce waking and sleep EEG changes. Pulse-modulated EMF exposure may provide a new, non-invasive method for modifying brain function for experimental, diagnostic and therapeutic purposes.

In two previous studies we demonstrated that radiofrequency electromagnetic fields (RF EMF) similar to those emitted by digital radiotelephone handsets affect brain physiology of healthy young subjects exposed to RFEMF (900 MHz, spatial peak specific absorption rate (SAR) 1 W/kg) either during sleep or during the waking period preceding sleep. In the first experiment, subjects were exposed intermittently during an 8 h nighttime sleep episode and in the second experiment, unilaterally for 30 min prior to a 3 h daytime sleep episode. Huber et al [8] reported an extended analysis of the two studies as well as the detailed dosimetry of the brain areas, including the assessment of the exposure variability and uncertainties. The latter enabled a more in depth analysis and discussion of the findings. Compared to the control condition with sham exposure, spectral power of the non-rapid eye movement sleep electroencephalogram (EEG) was initially increased in the 9-14 Hz range in both experiments. No topographical differences with respect to the effect of RF EMF exposure were observed in the two experiments. Even unilateral exposure during waking induced a similar effect in both hemispheres. Exposure during sleep reduced waking after sleep onset and affected heart rate variability. Exposure prior to sleep reduced heart rate during waking and stage 1 sleep. The lack of asymmetries in the effects on sleep EEG, independent of bi- or unilateral exposure of the cortex, may indicate involvement of subcortical bilateral projections to the cortex in the generation of brain function changes, especially since the exposure of the thalamus was similar in both experiments (approx. 0.1 W/kg).

Curcio et al [3] recorded the resting electroencephalogram of 20 healthy subjects in order to investigate the effect of electromagnetic field (EMF) exposure on EEG waking activity and its temporal development. The subjects were randomly assigned to two groups and exposed, in double-blind conditions, to a typical mobile phone signal (902.40 MHz, modulated at 217 Hz, with an average power of 0.25 W) *before* or *during* the EEG recording session. The results showed that, under real exposure as compared to baseline and sham conditions, EEG spectral power was influenced in some bins of the alpha band. This effect was greater when the EMF was on *during* the EEG recording session than *before* it. The present data lend further support to the idea that pulsed high-frequency electromagnetic fields can affect normal brain functioning, also if no conclusions can be drawn about the possible health effects.

The ubiquitous availability of mobile phone networks has fuelled the public discussion about possible adverse side effects. Previous studies investigating potential sleep disturbances caused by electromagnetic fields (EMF) emitted by mobile phones have yielded controversial results. Our study has aimed at identifying such effects in the context of EMF emitted by base stations. In a double-blind design, Hinrich et al [5] continuously applied a homogeneous, vertically polarized GSM 1800-type EMF (far-field characteristic: 1736-Hz pulse frequency) during 2 of 4 consecutive nights randomly to 13 healthy subjects. During sleep, polysomnographic recordings including 6 EEG channels were acquired. The sleep pattern of each individual night was derived from hypnograms by 2 independent raters, and afterwards collapsed over the 2 nights per field condition (i.e. EMF on or off). In addition, the EEG power spectra were individually estimated for each recording and separately for each of the sleep stages. The results failed to detect any statistically significant effect on human sleep in response to the EMF exposure. The hypothesis that sleep disturbances are related to EMF emitted from GSM 1800 base stations could not be supported in these settings.

Previous research has suggested that exposure to radiofrequency electromagnetic fields increases electroencephalogram spectral power in non-rapid eye movement sleep. Other sleep parameters have also been affected following exposure. Loughran et al [12] examined whether aspects of sleep architecture show sensitivity to electromagnetic fields emitted by digital mobile phone handsets. Fifty participants were exposed to electromagnetic fields for 30 min prior to sleep. Results showed a decrease in rapid eye movement sleep latency and increased electroencephalogram spectral power in the 11.5-12.25 Hz frequency range during the initial part of sleep following exposure. These results are evidence that mobile phone exposure prior to sleep may promote rapid eye movement sleep and modify the sleep electroencephalogram in the first non-rapid eye movement sleep period.

The erection of mobile telephone base stations in inhabited areas has raised concerns about possible health effects caused by emitted microwaves. In a cross-sectional study of randomly selected inhabitants living in urban and rural areas for more than one year near to 10 selected base stations, Hutter et al [11] investigated 365 subjects. Several cognitive tests were performed, and wellbeing and sleep quality were assessed. Field strength of high-frequency electromagnetic fields (HF-EMF) was measured in the bedrooms of 336 households. Total HF-EMF and exposure related to mobile telecommunication were far below recommended levels (max. 4.1 mW/m^2). Distance from antennae was 24-600 m in the rural area and 20-250 m in the urban area. Average power density was slightly higher in the rural area (0.05 mW/m^2) than in the urban area (0.02 mW/m^2). Despite the influence of confounding variables, including fear of adverse effects from exposure to HF-EMF from the base station, there was a significant relation of some symptoms to measured power density; this was highest for headaches. Perceptual speed increased, while accuracy decreased insignificantly with increasing exposure levels. There was no significant effect on sleep quality. Despite very low exposure to HF-EMF, effects on wellbeing and performance cannot be ruled out, as shown by recently obtained experimental results; however, mechanisms of action at these low levels are unknown.

Mobile phones signals are pulse-modulated microwaves, and EEG studies suggest that the extremely low-frequency (ELF) pulse modulation has sleep effects. However, 'talk', 'listen' and 'standby' modes differ in the ELF (2, 8, and 217 Hz) spectral components and specific absorption rates, but no sleep study has differentiated these modes. Hung et al [10] used a GSM900 mobile phone controlled by a base-station simulator and a test SIM card to simulate these three specific modes, transmitted at 12.5% (23 dBm) of maximum power. At weekly intervals, 10 healthy young adults, sleep restricted to 6 h, were randomly and single-blind exposed to one of: talk, listen, standby and sham (nil signal) modes, for 30 min, at 13:30 h, whilst lying in a sound-proof, lit bedroom, with a thermally insulated silent phone beside the right ear. Bipolar EEGs were recorded continuously, and subjective ratings of sleepiness obtained every 3 min (before, during and after exposure). After exposure the phone and base-station were switched off, the bedroom darkened, and a 90 min sleep opportunity followed. We report on sleep onset using: (i) visually scored latency to onset of stage 2 sleep, (ii) EEG power spectral analysis. There was no condition effect for subjective sleepiness. Post-exposure, sleep latency after talk mode was markedly and significantly delayed beyond listen and sham modes. This condition effect over time was also quite evident in 1-4 Hz EEG frontal power, which is a frequency range particularly sensitive to sleep onset. It is possible that 2, 8, 217 Hz modulation may differentially affect sleep onset.

To establish a dose-response relationship between the strength of electromagnetic fields (EMF) and previously reported effects on the brain, Regel et al [13] investigated the influence of EMF exposure by varying the signal intensity in three experimental sessions. The head of 15 healthy male subjects was unilaterally exposed for 30 min prior to sleep to a pulse modulated EMF (GSM handset like signal) with a 10 g-averaged peak spatial specific absorption rate of (1) 0.2 W kg^{-1}, (2) 5 W kg^{-1}, or (3) sham exposed in a double-blind, crossover design. During exposure, subjects performed two series of three computerized cognitive tasks, each presented in a fixed order (simple reaction time task, two-choice reaction time task (CRT), 1-, 2-, 3-back task). Immediately after exposure, night-time sleep was polysomnographically recorded for 8 h. Sleep architecture was not affected by EMF exposure. Analysis of the sleep electroencephalogram (EEG) revealed a dose dependent increase of power in the spindle frequency range in non-REM sleep. Reaction speed decelerated with increasing field intensity in the 1-back task, while accuracy in the CRT and N-back task were not affected in a dose-dependent manner. In summary, this study reveals first indications of a dose-response relationship between EMF field intensity and its effects on brain physiology as demonstrated by changes in the sleep EEG and in cognitive performance.

Conclusion

Acute exposure to a mobile phone prior to sleep significantly enhances electroencephalogram spectral power in the sleep spindle frequency range compared to the sham exposure condition. This mobile phone-induced enhancement in spectral power is largely transitory and does not linger throughout the night. Furthermore, a reduction in rapid eye movement sleep latency following mobile phone exposure was also found compared to the sham exposure, although interestingly, neither this change in rapid eye movement sleep latency or the enhancement in spectral power following mobile phone exposure, led to changes in the overall quality of sleep. In conclusion, a short exposure to the radiofrequency electromagnetic fields emitted by a mobile phone handset immediately prior to sleep is sufficient to induce changes in brain activity in the initial part of sleep. The consequences or functional significance of this effect are currently unknown and it would be premature to draw conclusions about possible health consequences.

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