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Changes in brain bioelectrical activity during active mobile phone use

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Mobile phones operate at relatively low levels of emitted radiofrequency and microwave energy during active use; however, under certain conditions, exposure to electromagnetic radiation may exceed prescribed safety limits. **The aim** of this study was to investigate the potential effects of high-frequency electromagnetic radiation emitted by an active mobile phone on the amplitude of EEG waves. **Materials and Methods:** The study included a total of 60 participants, comprising 30 males and 30 females. Each participant underwent two consecutive EEG recordings. The first recording was performed at rest, in the absence of any electromagnetic field source. Subsequently, EEG recording was repeated during active mobile phone use for 10 minutes on one ear and then on the contralateral ear. **Results:** Analysis of EEG amplitude in both male and female participants revealed no statistically significant differences in the variability of beta, theta, or delta wave amplitudes. The only parameter showing a statistically significant change was alpha wave amplitude, observed after mobile phone exposure in female participants, specifically over the nondominant hemisphere. **Conclusion:** Numerous studies have investigated the effects of active mobile phone use on the brain's bioelectrical activity, yielding results that are often inconsistent and sometimes contradictory. These discrepancies should not be viewed as limitations but rather as an impetus for further, methodologically refined research in this field, which should not be confined solely to brain electrical activity but should also address broader aspects of the impact of electromagnetic field exposure on overall human health.

Key words: EEG amplitude, mobile phone, brain bioelectrical activity

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Promena bioelektrične aktivnosti mozga tokom aktivne upotrebe mobilnog telefona

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Mobilni telefoni funkcionišu sa relativno niskim nivoima emitovane radiofrekventne i mikrotalasne energije tokom njihove aktivne upotrebe, ali u pojedinim uslovima može doći do prelaska propisane granične vrednosti izlaganja elektromagnetnom zračenju. Cilj ovog istraživanja bio je da se ispita mogući uticaj visokofrekventnog elektromagnetnog zračenja koje emituje aktivni mobilni telefon na amplitudu EEG talasa. Materijal i metod rada: u istraživanje je uključeno ukupno 60 ispitanika, od čega 30 osoba muškog i 30 osoba ženskog pola. Svakom ispitaniku izvedena su dva uzastopna EEG-a. Prvo snimanje obavljeno je u stanju mirovanja, bez prisustva izvora elektromagnetnog polja. Nakon toga EEG snimanje je ponovljeno tokom aktivne upotrebe mobilnog telefona u trajanju od 10 minuta na jednom uvu, a zatim na drugom. Rezultati: Analizom amplitude EEG-a kod ispitanika muškog i ženskog pola nije utvrđena statistički značajna razlika u varijabilitetu amplitude beta, teta i delta talasa. Jedini parametar koji je pokazao statistički značajnu promenu odnosio se na amplitudu alfa talasa i to nakon ekspozicije mobilnom telefonu kod ispitanica ženskog pola, na nedominantnoj hemisferi. Zaključak: Sprovedene su brojne studije o efektima aktivnih mobilnih telefona na bioelektričnu aktivnost mozga, a rezultati su često neujednačeni i ponekad međusobno protivrečni. Ove razlike u nalazima ne treba posmatrati kao ograničenje, već kao podsticaj za dalja, metodološki unapređena istraživanja u ovoj oblasti, koja ne bi trebalo da budu ograničena isključivo na električnu aktivnost mozga, već da obuhvate i šire aspekte uticaja izloženosti elektromagnetnim poljima na opšte zdravlje ljudi.

Ključne reči: EEG amplituda, mobilni telefon, bioelektrična aktivnost mozga

Introduction

With the introduction of GSM (Global System for Mobile Communications) technology, increased attention has been directed toward the effects of electromagnetic fields on the human organism. Although mobile phones operate at relatively low levels of emitted radiofrequency and microwave energy, during active use the antenna is typically positioned in close proximity to the user's head. Consequently, local exposure levels may reach—and under certain conditions even exceed—established regulatory limits for electromagnetic radiation exposure. Contemporary mobile radiocommunication systems operate within frequency bands of 900 MHz (GSM 900), 1800 MHz (GSM 1800), and approximately 2000 MHz (3G). Despite the widespread and intensive use of mobile phones, relatively little is known about their potential effects on human physiological processes. Owing to its sensitivity in detecting subtle functional changes potentially induced by these systems, electroencephalography (EEG) is most commonly employed.

EEG recording alone, however, has not been able to identify consistent effects, but it does suggest that the observed inconsistencies may be attributable to methodological limitations, thereby underscoring the need for the development of appropriate experimental models capable of examining the potential impact of exposure to active mobile phones on neuronal function. Although limitations in statistical data processing have likely influenced the outcomes of certain studies, the majority of published reports indicate that exposure to active mobile phones primarily affects neuronal responses that are not phase-locked to external stimuli, particularly under conditions requiring more complex cognitive processing (1,2). Nevertheless, this interpretation cannot fully account for all available experimental data. Given these inconsistencies, potential effects of electromagnetic radiation emitted by mobile phones are more readily identifiable using quantitative EEG analysis.

Quantitative electroencephalography (qEEG) represents a relatively modern methodological approach that enables the extraction of parameters not accessible through conventional visual EEG analysis. qEEG encompasses signal amplitude measurements, spectral analysis, correlation and coherence analyses, autoregressive methods, pattern recognition, statistical probability mapping, spatial and topographical analyses, dipole source localization techniques, electrical source analysis, automated event detection, as well as a range of other advanced analytical techniques (3,4).

The literature contains numerous contradictory reports regarding the relationship between mobile phone use and electroencephalographic (EEG) activity. A substantial number of studies suggest that such inconsistencies may arise from methodological differences, including exposure duration and the analytical approaches employed. Accordingly, the question has been raised as to why similar investigations yield divergent interpretations of results, with general assumptions proposing that findings obtained after short-term exposure may be of limited relevance and that observed effects may depend on exposure duration (5–7) or on the use of less sensitive analytical methods (e.g., basic spectral analysis) (6,8). An additional methodological challenge is the increase in variability associated with physiological changes in participants during prolonged exposure periods. For example, alpha activity is sensitive to fluctuations in alertness and attention; therefore, changes in vigilance during recording may lead to physiological variations in alpha activity that could be erroneously attributed to mobile phone exposure.

A substantial proportion of effects associated with mobile phone exposure demonstrate temporal dependence, suggesting that certain aspects of the observed changes are unlikely to represent a direct effect of the device on the EEG signal, but rather reflect alterations in neuronal function that are secondarily manifested in the EEG recording. This interpretation is supported by the fact that the emitted signal power of a mobile phone remains constant during exposure, whereas the EEG response exhibits dynamic changes over time (9).

Aim of the study

The primary objective of this study was to investigate the potential effects of high-frequency electromagnetic radiation emitted by an active mobile phone on the amplitude of EEG waves.

Materials and methods

A total of 60 participants were included in the study, comprising 30 males and 30 females, aged between 20 and 30 years. All participants had no history of neurological or psychiatric disorders and had not used any medications or psychoactive substances for at least one month prior to the beginning of the study. Consumption of alcohol and caffeine was prohibited for a period of four days prior to EEG recording and throughout the experimental protocol. Each participant served as his or her own control, with EEG recordings obtained before and after exposure to high-frequency electromagnetic radiation.

Each participant underwent two consecutive EEG recordings, each lasting approximately 20 minutes, separated by a break of about 5 minutes. The first recording was performed under resting conditions, in the absence of any electromagnetic field source. After a pause of approximately 3 minutes, EEG recording was repeated during active mobile phone use for 10 minutes on one ear, followed by a break of about 2 minutes and a subsequent recording with the mobile phone positioned on the contralateral ear, also for 10 minutes. A standard mobile phone was used as the source of high-frequency electromagnetic radiation.

Statistical analysis of the collected data was performed using computer-based statistical software. Descriptive statistical measures included the arithmetic mean with 95% confidence intervals, standard deviation, and minimum and maximum values. Group comparisons were conducted using exploratorydescriptive statistical procedures (Student's *t*-test) as well as confirmatory methods, including analysis of variance (ANOVA) and the *t*-test.

Results

The study included a total of 60 participants (30 males and 30 females). The analyzed parameters were changes in the mean amplitude of EEG waves before and after exposure to an active mobile phone, assessed separately for each side of exposure.

The mean values and variability of EEG wave amplitudes in males on the right ear before and after mobile phone exposure are presented in Table 1. The arithmetic mean and standard deviation of alpha-wave amplitude in males on the right ear prior to mobile phone exposure were 13.9 ± 3.4, increasing to 14.8 ± 3.5 after exposure; however, this difference was not statistically significant (t = 1.764; p = 0.088). The mean and standard deviation of beta-wave amplitude before exposure were 2.5 ± 1.0, compared with 2.2 ± 0.9 after exposure, with no statistically significant difference observed (t = 1.754; p = 0.090). For theta-wave amplitude, the mean ± standard deviation prior to exposure was 1.4 ± 0.6, increasing to 1.5 ± 0.5 following exposure; this change was not statistically significant (t = 1.710; p = 0.098). Similarly, the mean ± standard deviation of delta-wave amplitude before exposure was 1.7 ± 0.7 and remained unchanged after exposure at 1.7 ± 0.8, with no statistically significant difference (t = 0.078; p = 0.938).

Table 1. Mean values and variability of amplitude in male participants at the right ear before and after exposure to a mobile phone

Waves	Measurement	as	sd	med	min	max	p
Alpha	before	13,9	3,4	12,7	9,8	21,0	0,088
	after	14,8	3,5	14,7	9,8	23,9	
Beta	before	2,5	1,0	2,1	1,1	4,8	0,090
	after	2,2	0,9	2,1	0,7	4,1	
Theta	before	1,4	0,6	1,1	0,5	2,9	0,098
	after	1,5	0,5	1,5	0,9	2,7	
Delta	before	1,7	0,7	1,7	0,9	3,3	0,938
	after	1,7	0,8	1,7	0,3	3,8	

The mean values and variability of EEG wave amplitudes in males on the left ear before and after mobile phone exposure are presented in Table 2. The arithmetic mean and standard deviation of alpha-wave amplitude in males on the left ear prior to exposure were 7.6 ± 1.0, compared with 7.5 ± 0.9 after exposure, with no statistically significant difference observed (t = 0.220; p = 0.828). The mean ± standard deviation of beta-wave amplitude before exposure was 1.9 ± 0.8 and remained 1.9 ± 0.5 after mobile phone exposure, showing no statistically significant difference (t = 0.191; p = 0.850). For theta-wave amplitude, the mean ± standard deviation prior to mobile phone use was 1.4 ± 0.6, decreasing to 1.3 ± 0.6 after exposure; this change was not statistically significant (t = 1.085; p = 0.287). Similarly, the mean ± standard deviation of delta-wave amplitude before exposure was 1.3 ± 0.6 and remained unchanged after mobile phone use at 1.3 ± 0.5, with no statistically significant difference (t = 0.436; p = 0.666).

Table 2. Mean values and variability of amplitude in male participants at the left ear before and after exposure to a mobile phone

Waves	Measurement	as	sd	med	min	max	P
Alpha	before	7,6	1,0	7,5	5,1	9,1	0,828
	after	7,5	0,9	7,6	4,5	9,0	
Beta	before	1,9	0,8	1,9	1,0	4,8	0,850
	after	1,9	0,5	2,0	1,1	2,9	
Theta	before	1,4	0,6	1,1	0,5	2,9	0,287
	after	1,3	0,6	1,1	0,4	2,8	
Delta	before	1,3	0,6	1,2	0,6	3,0	0,666
	after	1,3	0,5	1,2	0,2	2,9	

The mean values and variability of EEG wave amplitudes in females on the right ear before and after mobile phone exposure are presented in Table 3. The arithmetic mean and standard deviation of alpha-wave amplitude in females on the right ear prior to mobile phone exposure were 14.6 ± 3.7, increasing to 15.7 ± 3.9 after exposure; this difference was statistically significant (t = 2.723; p = 0.011). The mean ± standard deviation of beta-wave amplitude before exposure was 2.4 ± 0.8 and decreased slightly to 2.3 ± 0.8 after exposure; however, this change was not statistically significant (t = 0.846; p = 0.405). For theta-wave amplitude, the mean ± standard deviation prior to exposure was 1.6 ± 0.8, increasing to 1.8 ± 0.6 following exposure, with no statistically significant difference observed (t = 1.151; p = 0.259). Similarly, the mean ± standard deviation of delta-wave amplitude before exposure was 1.7 ± 0.7 and increased to 1.8 ± 0.6 after exposure; this difference did not reach statistical significance (t = 1.975; p = 0.058).

Table 3. Mean values and variability of amplitude in female participants at the right ear before and after exposure to a mobile phone

Waves	Measurement	as	sd	med	min	max	p
Alpha	before	14,6	3,7	13,6	8,0	24,0	0,011
	after	15,7	3,9	14,0	11,8	27,8	
Beta	before	2,4	0,8	2,3	0,9	4,1	0,405
	after	2,3	0,8	2,3	0,9	4,3	
Theta	before	1,6	0,8	1,7	0,4	3,1	0,259
	after	1,8	0,6	1,9	0,6	2,9	
Delta	before	1,7	0,7	1,7	0,3	3,1	0,058
	after	1,8	0,6	1,9	0,3	2,9	

Table 4 presents the mean values and variability of EEG wave amplitudes in females on the left ear before and after mobile phone exposure. The arithmetic mean and standard deviation of alpha-wave amplitude in females on the left ear prior to exposure were 7.2 ± 0.7, compared with 7.1 ± 0.5 after exposure, with no statistically significant difference observed (t = 0.825; p = 0.416). The mean ± standard deviation of beta-wave amplitude before mobile phone exposure was 1.6 ± 0.5 and decreased to 1.5 ± 0.5 after exposure; however, this difference was not statistically significant (t = 1.664; p = 0.107). For theta-wave amplitude, the mean ± standard deviation prior to exposure was 1.4 ± 0.6 and remained 1.4 ± 0.5 following exposure, with no statistically significant difference (t = 0.779; p = 0.442). Similarly, the mean ± standard deviation of delta-wave amplitude before exposure was 1.3 ± 0.5 and increased slightly to 1.4 ± 0.4 after mobile phone exposure; this change was not statistically significant (t = 1.115; p = 0.274).

Table 4. Mean values and variability of amplitude in female participants at the left ear before and after exposure to a mobile phone

Waves	Measurement	as	sd	med	min	max	p
Alpha	before	7,2	0,7	7,1	5,1	8,8	0,416
	after	7,1	0,5	7,1	5,9	8,0	
Beta	before	1,6	0,5	1,6	0,9	2,4	0,107
	after	1,5	0,5	1,6	0,8	2,6	
Theta	before	1,4	0,6	1,2	0,3	2,9	0,442
	after	1,4	0,5	1,3	0,4	2,7	
Delta	before	1,3	0,5	1,1	0,4	2,4	0,274
	after	1,4	0,4	1,2	0,8	2,1	

Discussion

The present study was limited to 10-minute mobile phone exposure on each ear, during which EEG activity was continuously monitored. Rodney J. Croft and colleagues (10) conducted investigations specifically focusing on exposure-duration–dependent changes. In our results, no statistically significant changes in EEG activity were observed following mobile phone exposure compared with the non-exposure period, which may be explained, at least in part, by the relatively short duration of exposure. Findings that are not largely consistent with our results include studies reporting that exposure to electromagnetic fields may induce changes in brain electrical activity (11,12). In contrast, several authors have reported that active mobile phone use does not result in measurable changes in EEG recordings (13,6).

Lebedeva NN and colleagues (11) conducted an experimental study involving 24 healthy volunteers to assess EEG responses to mobile phone electromagnetic field exposure. Each participant underwent two recordings: one during real mobile phone exposure and another under placebo conditions, similar to our protocol but with a longer exposure duration of 15 minutes. The authors reported a statistically significant increase in the global correlation dimension during exposure, which was interpreted as a manifestation of cortical activation induced by the active electromagnetic field of the mobile phone (12). Hietanen M. and colleagues (13) investigated the potential effects of radiofrequency radiation emitted by mobile phones on human brain function using quantitative EEG analysis. Their study included 19 volunteers, with five different mobile phones—both analog and digital—used as exposure sources. The duration of the real exposure phase was 20 minutes. The results demonstrated that exposure to one of the tested devices led to a statistically significant change in absolute power within the delta frequency band. However, no changes were observed in other frequency bands, and the authors concluded that radiofrequency fields emitted by mobile phones do not exert abnormal effects on human EEG activity, suggesting that the isolated significant finding was most likely attributable to statistical variability. Our results similarly demonstrated a change in only a single frequency band.

Comparable inconsistencies observed in wakefulness have also been reported in studies examining EEG activity during sleep, where some investigations identified effects of exposure to active mobile phones (14), whereas others did not observe significant changes (15). Curcio G. and colleagues (16) analyzed EEG activity in 20 healthy volunteers to evaluate the effects of electromagnetic field exposure on EEG parameters and their temporal dynamics. Participants were randomly assigned to two groups and examined using a double-blind protocol, with exposure to signals corresponding to typical mobile telephony characteristics (902.40 MHz). The results indicated that real exposure, compared with control conditions, led to changes in EEG spectral power, particularly within specific alpha rhythm sub-bands, which is consistent with the findings of our study. The observed effects were more pronounced when the electromagnetic field was active during EEG recording compared with the pre-exposure period. These findings further support the hypothesis that pulsed high-frequency electromagnetic fields may influence the physiological organization of brain activity. Although our study was conducted in awake participants, similar changes in EEG spectral power density have also been reported during sleep (17,18).

Perentos N. and colleagues (19), in contrast to our findings, did not detect changes in alpha spectral power during exposure to radiofrequency radiation emitted by mobile phones. Their study included 12 participants and focused on assessing potential increases in alpha-band power following exposure, using a dipole antenna as the radiation source with characteristics approximating those of a real GSM device. The exposure duration was 15 minutes. EEG analysis did not reveal any alterations in the alpha spectrum.

Loughran SP and colleagues (20) investigated the potential increased sensitivity of the adolescent population to radiofrequency electromagnetic fields emitted by mobile phones. The study included 22 participants aged 11 to 13 years, who underwent three experimental sessions involving exposure to radiofrequency electromagnetic fields characteristic of mobile telephony at two different intensity levels. Analysis of EEG parameters did not demonstrate statistically significant changes attributable to radiofrequency exposure. Nevertheless, the authors emphasized that their findings provide a basis for further research, particularly with regard to potential effects of mobile phone use on cognitive functions during developmental periods.

Conclusion

Analysis of EEG amplitude in male and female participants before and after exposure to electromagnetic fields emitted by an active mobile phone did not reveal statistically significant differences in the variability of beta, theta, or delta wave amplitudes. The only parameter demonstrating a statistically significant change was alpha-wave amplitude, observed after mobile phone exposure in female participants on the non-dominant hemisphere. As demonstrated by numerous previous studies employing diverse methodological approaches and examining parameters comparable to those analyzed in the present investigation, results in this field are often inconsistent and occasionally contradictory. These discrepancies should not be regarded as limitations, but rather as an incentive for further, methodologically refined research in this area, which should not be restricted solely to brain electrical activity but should also encompass broader aspects of the impact of electromagnetic field exposure on overall human health.

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