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The effect of short-term electromagnetic fields caused by mobile phones on the electrical activity of alpha and beta brain waves

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Abstract
Aim: The widespread use of mobile phones by people is increasing in society. The effect of these areas on neurophysiological and EEG is intriguing. In this study, we aimed to investigate the effect of short-term cell phone-induced electromagnetic field on the electrical activity of the EEG alpha and beta bands in the human brain.
Materials and Methods: The study was carried on twenty males divided into four groups such as Group 1: eyes closed (10 sec), Group 2: eyes open (10 sec), Group 3: phone exposure (3 min) and Group 4: control group (no phone, 3 min).
Results: In our study, no significant change was observed in the EEG electrical activity of the alpha waves between mobile phone use and non-use ($p>0.05$). As a result of the analysis made for the beta waves, in the comparison between the group exposed to the mobile phone and the non-exposed group, there was a significant difference between the FFT max F and PSD max power parameters ($p<0.05$), and an insignificant difference between the FFT max value and PSD max F parameters was found ($p>0.05$).
Discussion: The use of mobile phones can lead to some changes in the electrical activity of some bands of the brain.

Keywords
Mobile phone; Radiofrequency; Electromagnetic field; Alpha wave; Beta wave; Brain electrical activity

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Introduction

The spread of new electronic devices is the effect of technology so that it is impossible for people to avoid the electromagnetic exposure caused by the use of these tools. The most widely used of these tools are mobile phones. According to 2017 data, there are approximately 8 billion mobile phone users worldwide [1]. Mobile communication technologies are based on radiofrequency electromagnetic field. Studies are carried out in different areas related to the possible biological effects of these areas. These are in vivo, in vitro, experimental human studies, and epidemiological studies. After all the evidence has been reviewed, radiofrequency electromagnetic fields are classified as possible carcinogens for humans by the IARC (the International Agency for Research on Cancer) [2].

Possible changes in electroencephalography were investigated with the use of mobile phones by medical students. In empirically researched studies, it was emphasized that mobile phones can cause some EEG changes and some bad effects on the well-being of the users [3]. When brain cells are active, it causes local currents to form in the environment. EEG measures the electrical potential changes flowing. There are 10-20 reference points which are determined internationally for registration, and recording is done with electro cap and AG/AgCI electrodes [4]. Electroencephalography (EEG) detects electrical activities that occur in the brain itself, recorded with multiple electrodes placed on the scalp [5].

In healthy adults, the amplitudes and frequencies of the electrical signals that occur in the brain can vary from one human condition, such as wakefulness and sleep. The characteristics of the waves can also change with age. Five major brain waves with different frequency ranges are observed in EEG. From low to high frequencies, these frequency bands consist of delta (δ), theta (θ), alpha (α), beta (β) and gamma (γ), respectively [6]. Electromagnetic radiation is reported to affect the EEG frequency bands in the power spectrum of alpha, theta, delta, beta and gamma bands [7]. As a result of short-term (approximately 3.5 minutes) exposure of 900 MHz electromagnetic field, it is reported that it does not cause any change in spectral power intensity in awake EEGs [8]. In the research carried out by the researchers on brain electroencephalography of the cell phone-induced electromagnetic field, it was reported that visible and measurable changes were observed in all five brain waves with short-term exposure time [9].

In light of the above-mentioned discussions, the aim of our study is to investigate whether healthy young people exposed to radiofrequency electromagnetic fields published on mobile phones are at any risk. Thus, in our study, we hypothesized whether short-term cell phone exposure changes in the electrical activity of frequency and power spectral densities for alpha and beta waves that occur during the rhythmic activity of the brain.

Material and Methods

Subjects

This study was conducted on 20 healthy male subjects aged 18-28 years (mean±SD: 21.15±2.10). All subjects included in the study were healthy and did not have any disease or neurological history. Subjects were kept away from drugs, caffeine, and alcohol before the study and they were asked to take regular sleep. The subjects were informed about the study and voluntary consent forms were filled and their consents were obtained before starting the study. They stated that the subjects used their cell phones less than 20 minutes per day. The approval of the Clinical Research Ethics Committee of the Kırsehir Ahi Evran University Faculty of Medicine was taken (2019-07/85). The experiment was carried out according to the Declaration of Helsinki.

Exposure system and grouping

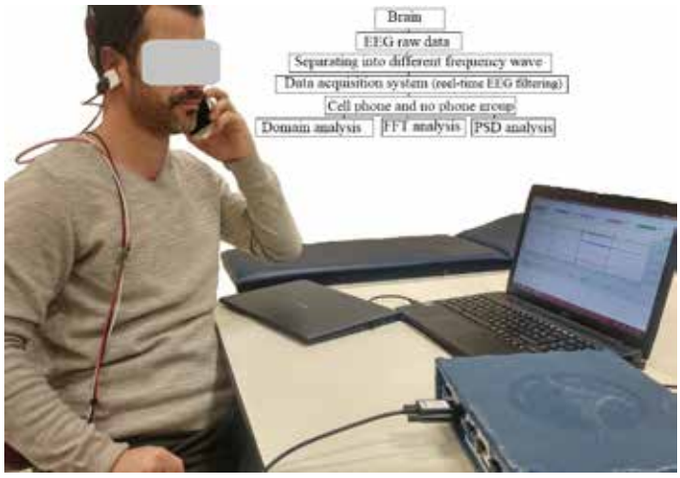
A standard commercial mobile phone was used (HTC Cor., Desire 610n, Taoyuan, Taiwan); 900 MHz, the SAR value of head for 10 g tissue: 0.346 W/kg, the SAR value for the body of 10 g tissue: 0.336 W/kg. The subjects used their right hands and held mobile phones to their right ears for conversation. Four groups were formed for alpha and beta waves as follows: Group 1: eyes closed, Group 2: eyes open, Group 3: three minutes talking by cell phone and Group 4: control group (no phone). Electromagnetic field measurement was performed with PCE EM-29 electromogmeter. The electric field was 49.02 V/m, the magnetic field was 243.1 mA/m, and the energy density was 11.80 mW/m2 [3, 8, 9].

Experimental procedure and EEG data acquisition

This study was carried out in the Biophysics research laboratory of Faculty of Medicine, Kırşehir Ahi Evran University. Biopac MP36 Student Lab instrument (BIOPAC System Inc., Goleta, CA, USA) and AcqKnowledge 4.1 software were used in the study. The Biopac electrode set (SS2L) was connected to CH1 of the MP36. The Biopac disposable vinyl electrodes (EL 503) were placed on the T3 and T5 region in the 10-20 International electrode system. During the recording, the subjects were seated in the chair and remained motionless. Electrode conductivity was measured as 5.38 kohms. Domain measurements, FFT, and power spectral densities of EEG signals were measured. The measured raw EEG signals were subdivided. Time-domain characteristics and FFT and PSD measurements were performed for alpha and beta waves. FIR, High pass filters, hand movements and other noises were removed. For domain measurements, 2048 point of FFT, cell phone 65560 point of FFT, pad with zeros, magnitude, linear, window: hamming, PSD, Windows: Hamming operations were applied. Figure 1 shows the experiment protocol. While recording, the mobile phone was kept open and being held to the subject's ear. The subjects remained silent to prevent muscle activity and parasites from forming.

Data analysis

Statistical analysis of the study was performed using Statistical Package for Social Sciences version 21.0 software for Windows (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp., USA). The normality assumption was tested by the Kolmogorov-Smirnov and the Shapiro-Wilk tests. Descriptive statistics of the variables are given as mean error standard deviation. Paired t test and Wilcoxon matched-pair test were used for univariate analysis of dependent variables.



Eyes closed	Eyes open	Phone exposure	No phone
10 sec	10 sec	3 min	3 min

Figure 1. The experimental protocol

Results

In our study, 20 healthy men were included. They used mobile phones adhered to the right ears of the subjects. The effects of mobile cell phones on EEG alpha and beta waves were investigated. Average, min, max, std, skew, kurtosis, FFT (Max F, Max value), PSD (Max F and Max power) parameters were examined, and recording was done in four stages (eye closed and open, mobile phone exposure and no exposure recording). In the study, the frequency range of the Alpha waves was found in the normal range (8-12 Hz). In our study, we found 10.55 Hz with eyes closed, 11.04 Hz with eyes open, GSM-EMF group 10.86 Hz, control group (no phone) 9.91 Hz. No significant change in power spectral densities was observed. The frequency range of the beta wave was in the normal range (13-30 Hz). In our study, eyes were closed 15.33 Hz, eyes were open 19.11 Hz, GSM-EMF group 18.13 Hz, control group (no phone) 20.72 Hz. A significant increase in power spectral density was observed in the group using mobile phones.

The results of the alpha waves are given in Table 1. According to these results, there is a statistically significant difference in terms of FFT max value and PSD max power variables with eyes open and eyes closed ($p<0.05$). In terms of FFT max F and PSD max F variable, there was no significant difference between

Table 1. Statistical comparison of FFT and PSD variables of alpha waves

		Eyes-open			Eyes-closed			P
		Median	Min	Max	Median	Min	Max	
Alpha waves	FFT Max (μV)	0.268	0.128	0.464	0.543	0.226	1.575	0.000*
	FFT Max F (Hz)	11.035	8.389	15.771	10.107	8.593	14.648	0.263
	PSD Max F (Hz)	10.699	7.782	14.785	10.116	8.560	13.229	0.200
	PSD Max Power (μV^2/Hz)	0.007	0.002	0.033	0.035	0.005	0.169	0.001*
		Phone exposure			No phone			
		Median	Min	Max	Median	Min	Max	
Alpha waves	FFT Max (μV)	0.051	0.029	0.110	0.052	0.030	0.136	0.826
	FFT Max F (Hz)	10.890	8.279	13.424	10.649	8.154	12.401	0.279
	PSD Max F (Hz)	10.531	8.274	13.033	9.805	8.713	12.423	0.097
	PSD Max Power (μV^2/Hz)	0.013	0.004	0.082	0.014	0.004	0.200	0.672

*p<0.05 was accepted as statistically significant. FFT: Fast Fourier transform, Max: maximum, PSD: power spectrum density. Data are presented as median, min and max.

Table 2. Statistical comparisons of FFT and PSD variables of beta waves

		Eyes-open			Eyes-closed			P
		Median	Min	Max	Median	Min	Max	
Beta waves	FFT Max (μV)	0.251	0.121	0.635	0.311	0.172	0.554	0.213
	FFT Max F (Hz)	18.993	13.769	25.685	14.013	9.863	28.417	0.011*
	PSD Max F (Hz)	16.984	14.785	24.902	14.980	9.727	26.070	0.035*
	PSD Max Power (μV^2/Hz)	0.007	0.001	0.224	0.012	0.004	0.036	0.501
		Phone exposure			No phone			
		Median	Min	Max	Median	Min	Max	
Beta waves	FFT Max (μV)	0.040	0.024	0.181	0.043	0.034	0.088	0.532
	FFT Max F (Hz)	18.252	14.425	22.589	21.092	15.316	25.309	0.005*
	PSD Max F (Hz)	18.598	11.229	23.213	18.739	15.572	26.409	0.097
	PSD Max Power (μV^2/Hz)	0.008	0.002	0.199	0.014	0.004	0.077	0.015*

*p<0.05 was accepted as statistically significant. FFT: Fast Fourier transform, Max: maximum, PSD: power spectrum density. Data are presented as median, min and max.

eyes open or eyes closed (p>0.05). There is no difference between mobile phone speech and 3 minutes fixed recording in terms of all variables of alpha waves (p>0.05).

The analysis results obtained for the beta waves are summarized in Table 2. In our study, there was no significant difference between eyes closed or eyes open in terms of FFT max and PSD Max power variables (p>0.05). The FFT max F value in eyes open group was found to be lower than the FFT max F value when the eyes were closed (p<0.05). In terms of PSD max F variable, the values measured when the eyes are open are lower than the values measured when the eyes are closed, and the difference was statistically significant (p<0.05). A statistically significant difference was detected between FFT max F and PSD max power parameters of a mobile phone (phone exposure) and non-mobile groups (no phone) (p<0.05). There was no significant change between the other parameters of these groups (p>0.05).

Discussion

In an experimental study on rats, cell phone exposure at different frequencies (900, 1800 and 2100 MHz) was created, and as a result of the study, an increase in oxidative DNA damage in rat brain tissues after the radiation emitted by the cell phones was reported [20]. Fourteen published studies on the effect of GSM mobile phone exposure on brain electrical activity and sleep change have been compiled. When the findings of the study are analyzed, it is reported that there are no changes in three studies and eleven studies have caused changes in brain activities [10]. When another similar study was examined, it was reported that 20% of mobile phones had no effect on brain activity, 3% were reported to affect only beta and gamma bands, 30% had an effect on alpha and other frequency bands, and 47% had only one alpha band change [1]. A 5-minute exposure (before, during, and after) was established using a commercial mobile phone on 30 healthy subjects. The result of the study provides evidence that mobile phone use affects brain waves (alpha and beta) [11]. In our study, it is seen that both alpha and beta waves can cause activity change in the brain when the minimum, maximum, skew and kurtosis parameters are examined.

In humans, 15 minutes of electromagnetic field exposure from a mobile phone was made. It has been reported that exposure at the T3 position does not cause a statistically significant change in the bioelectric activity occurring in the human brain [12]. The effect of GSM-EMF fields on young and old people was investigated. In the study, it was reported that there was a significant increase in alpha rhythms in the frontal region in the elderly. It shows that mobile phone-induced EMF affects interhemispheric synchronization [13]. As a result of the research, they stated that electromagnetic fields originating from mobile phones affect the human brain and that GSM-powered mobile phones may have a higher effect on brain activity than CDMA-powered mobile phones [5]. A decrease in the EEG alpha power band was detected in eyes-closed position during and after 900 MHz GSM-EMA exposure on 26 healthy volunteers [14]. The effect of ELF-MF field (100 μT) on EEG parameters was investigated in 19 men. In the study, a decrease in the strength of the beta band and an increase in the alpha band were observed in eyes closed exposure. A reduction in the power spectrum of the alpha band was observed with eyes open exposure [15]. In our study, compared to the group not using the mobile phone, an increase in maximum data of alpha rhythms, and a significant change in FFT and PSD parameters were not observed. A statistically significant difference was found in the FFT max F value and PSD max power values of the beta waves. They stated that the 20-minute RF-electromagnetic field created using a commercial mobile phone caused a reduction in the alpha frequency band [16]. Another 20-minute study reported that exposure to 3G and 4G mobile cell phones on 60 healthy volunteers may have some local biophysical effects [17]. In our study, there was no correlation with long-term exposures because there was a short-term exposure. However, there was no significant statistical difference in the alpha band.

The high strength of the increased beta waves causes stress, anxiety, and some physical and mental discomfort [7]. The effect of heavy and medium cell phone use on brain EEG was investigated. Researchers have not observed a slowdown in brain activity and a significant effect on the beta waves [18]. Croft et al. reported that acute cell phone exposure could alter rest EEG, and also reported no EMF effect in theta, beta or gamma bands in the study [19]. In our study, PSD max power value in the group using mobile phones increased compared to the group not using phones and was found statistically significant.

Conclusion

In the literature, different reports on the effect of mobile phone use on brain electrical activity are published. In our study, the short-term effects of cell phone-induced electromagnetic field on brain waves were examined and no statistically significant change was observed in the parameters of the electrical activity of the alpha waves as a result of this short exposure, but as a result of Fast Fourier transform and power spectral density analysis of the electrical activity of the beta waves, there was a statistical difference. The source of possible changes due to mobile phones mentioned in the literature data is uncertain. It is therefore a matter of debate whether these changes are due to movement of people during EEG recording, whether they are due to the recording device, environmental noise, or people's current thinking activity. Therefore, studies on short and long term detailed EEG activity of electromagnetic fields originating from mobile phones are needed.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest

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