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휴대폰 전자장 노출로 인한 뇌의 EEG 와 BAEP 연구

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A Study on EEG and BAEP Test of Human Brain During Exposure to Cellular Phone

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본 연구조사는 전자파의 인체영향을 파악하고자 휴대폰 사용으로 인한 마이크로파 노출에 따른 인간 뇌의 전기적 기능의 잠재적인 영향을 파악하고자 2002년 2월 초순부터 3월 말까지 수행되었다. 연구대상자는 7년 이상의 휴대폰 장기 사용자 10명과 2년 이하의 단기 사용자 10명을 대상으로 뇌파 검사(EEG)와 뇌간청각유발전위검사(BAEP)를 통해 조사하였다. 휴대폰 장기 사용자와 단기 사용자간의 뇌파검사(EEG)를 실시하여 뇌 전위 전력분포 강도를 전극별로 분석한 결과, 휴대폰 장기 사용자의 휴대폰 사용 중과 비 사용 및 휴대폰 단기 사용자의 휴대폰 비 사용 간에는 통계적으로 유의한 차이가 나타나지 않았다(P〉 0.05). 또한, 청각기능을 잠복기로 분석한 결과 절대 잠복기와 파간 잠복기 모두에서 통계적으로 유의한 차이는 나타나지 않았으나 (P>0.05), 휴대폰 장기 사용자의 휴대폰 사용 중과 비 사용에서는 파형 Ⅴ에서 통계적으로 유의한 차이를 나타내어 (P 〈 0.05), 장기간의 휴대폰 사용으로 인해 청각기능에 영향을 줄 수 있음을 시사하였다.

Key Words : Microwave, Cellularphones, Electroencephalogram(EEG), Brainstem Auditory Evoked Potential (BAEP)

Ⅰ. Introduction

The use of cellularphones has increased exponentially during the past decade in Korea and public concern regarding emitting from cellularphones has increased as well the possible health effects from exposure to microwave(MW) fields. In response to public concern over health effects of electromagnetic field exposure, the World Health Organization(WHO) established the International EMF Project in 1996. WHO has been conducted into possible health effects of exposure to radiofrequency fields and will publish Environmental Health Criteria(EHC) reviews of the scientific literature on RF fields. The WHO EHC on RF has advanced following various scientific studies. The EHC on RF fields is expected in 2007. So, we executed the human's EEG(electroencepha-logram) and BAEP(brainstem auditory evoked potentials) test in compensation for cellular phone users to study microwave effects on nervous system.

The concern is whether MW exposure from cellular phones has the potential to influence the electrical functions of the human brain(Graham et al., 1994). Exposure to microwave electromagnetic(EM) radiation can cause behavioral changes in humans and

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Table 1. Experimental protocols

Test procedure	Species	RF exposure	Remark
A	10 subjects in long-term cellularphone users(more than 7 years)	Frequency: 800-1800 MHz, right ear	Normal use position right side of head
B	10 subjects in long-term cellularphone users(more than 7 years)	No exposure	Control to A
C	10 subjects in short-term cellularphone users(less than 2 years)	No exposure	Control to A, B

experimental animals (DAndrea, 1991). Which indicates that the central nervous system(OConnor, 1988), and in particular the brain may be affected.

The measurement of brain electrical activity, the EEG during behavioral tasks offers several unique advantages for studying the effect of EM on the electrical activity of the brain. One of these is the excellent time resolution of the EEG. Direnfeld has suggested the dominant brain wave frequencies may be the evolutionary result of the presence and the effect of low-level EM energy on the nervous system (Direnfeld, 1983). Small differences in the balance of activation between hemispheres are more significant for behavior than the total level of brain activation (Davison, 1988). There has been some work on long-term changes of EEG asymmetry were observed (Kholodov & Levedeva, 1992) and short-term effects of weak MW field exposure (Adey, 1981). The clinical usefulness of BAEPs often depends on a stable and well-defined wave Ⅴ. The resolution of wave Ⅴ within the Ⅳ/Ⅴ complex, however, varies among normal subjects when recorded between the vertex and ear ipsilateral to stimulation (A_I-C_Z) (Chiappa et al., 1979). This normal variability can be the basis for high interpeak latency(IPL) differences between trials and sessions, particularly when a single-peaked Ⅳ/Ⅴ complex is present. Previous studies have demonstrated that BAEP wave forms recorded between the vertex and ear contralateral to stimulation (A_C-C_Z) differ from those of the A_I-C_Z channel, but they did not determine whether the A_C-C_Z Ⅳ/Ⅴ complex is more stable (Stockard, 1978; Prasher, 1980; Robinson, 1981). In this study, BAEPs from these 2 channels were recorded simultaneously and compared in order to determine the value of A_I-C_Z recordings in improving IPL reliability and enhancing wave form stability.

The purpose of this study was to evaluate the effects of microwave exposure on the electrophysiologic functions in the human brain between long-term and short-term cellular phone user.

Ⅱ. Materials and methods

A. Subject

Subjects were 20 physically and mentally healthy male volunteers who were 24-35 years of age, 173.9±2.5 ㎝ in height and 69.1±9.8 ㎏ in weight, and 22.54±4.4 ㎏/㎡ in body mass index (BMI).

All volunteers provided written informed consent. Subjects were assigned to two group; 10 subjects in long-term cellular-phone users (more than 7 years) and 10 subjects in short-term cellular users (less than 2 years).

B. Experimental condition

We use cellular phone as RF exposure source. Table 1 indicated test procedure of this study. We divided test procedure into 3 processes. Test A was process of long-term uses which was exposed by RF energy from cellular phone. This test group was used to analyze complex effect of acute and chronic RF exposure. Test B was applied to research only acute RF exposure, and test C group was used to contrast with A and B. In case of test A process, volunteers used cellular phone of their own for EEG and BAEP testing.

C. Electroencephalograms(EEG) test

From February to March 2002, double EEG test (procedure A and B) were performed on the 10 long term cellular phone users, and single EEG test (procedure C) was performed on the 10 short-term users. Each EEG recording session lasted for 40 minutes after 30 minutes of exposure and a 10 minute post-exposure period. EEG were recorded with NEVROFAX instruments.

Figure 1 indicated schematic representation of the EEG experimental system. EEG activity was cortices using a 16-channel polygraph with the recorded simultaneously from both symmetrical bandwidth set at 1 to 70 Hz. The frequency spectra of 10-sec successive EEG epochs in the range of 1 - 70 Hz were analyzed "on-line" on an IBM-compatible PC/386 personal computer. Each epoch was digitized with a multichannel A/D DT 2821 converter using a sampling rate of 20 and

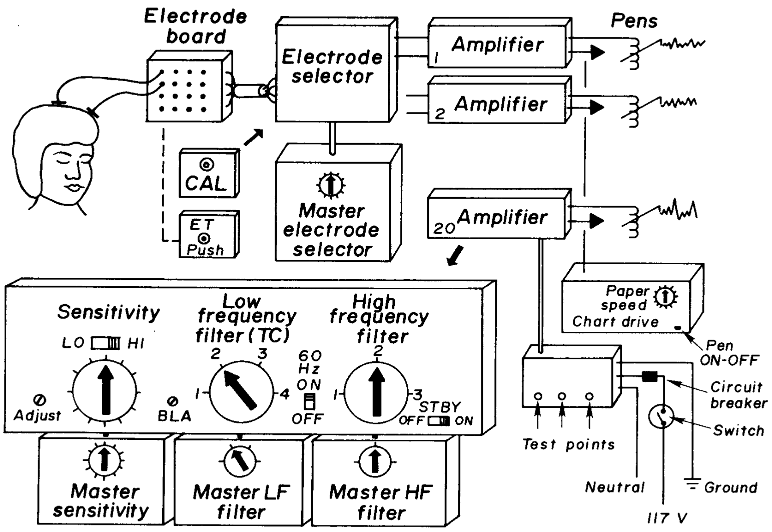

Fig 1. Schematic representation of the EEG experimental system.

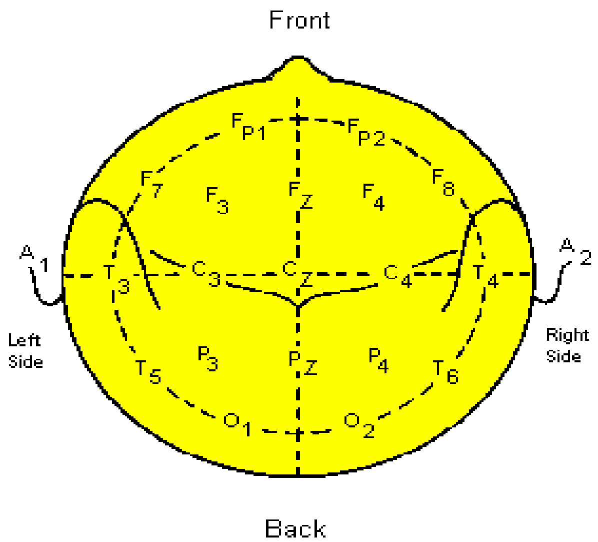

Fig 2. Test positions of EEG according to the standard 10-20 Electrode placement system.

resulting in 200 sampling points. The EEG recordings were performed on subjects in a prone position, during relaxed but alert wakefulness, with eyes closed.

Figure 2 showed test positions of EEG according to the standard 10-20 electrode placement system. The monopolar EEG derivations were measured with Ag/AgCl surface electrodes fixed at the positions C_3, C_4, F_3, F_4, P_3, and P_4, according to the international 10-20 electrode placement system. The 6 test positions were selected to compare the brain wave's difference of right hemisphere with left hemisphere according to using cellular phone. The raw EEG power spectra of each hemisphere were averaged for successive 10-sec periods in all subjects both before and during exposure.

The EEG asymmetry was calculated by comparing the power values in each frequency band from left and right hemispheres as a ratio. For quantitative assessment of these spectra, the mean spectral power density was calculated in distinct frequency ranges(Herrmann, 1989) : Δ(1~3.5 Hz), θ(3.5~7.5 Hz), α(7.5~12.5 Hz), and β(12.5~18.0 Hz). Statistical analysis was based on these spectral parameters. Differences were considered statistically significant at a $P < .05$ using the T-test.

D. Brainstem Auditory Evoked Potentials(BAEP) test

BAEPs were recorded from 20 volunteers. Silver-silver chloride electrodes were placed on the vertex (C_Z), the medial aspect of ears (A_I) and the forehead. Recorded activity was amplified and filtered with a bandpass of 100~2,000 Hz. The analyzed epoch was 10 msec after the onset of the stimulus. Two trials of 2,000 responses each were obtained and analyzed for each ear tested. Stimuli were presented to the left ear for 2 trials and then to the right ear, first at a level of 90 dB and then at 110 dB.

Figure 3 displayed the BAEP experimental system and place. The headphones were shielded and contained piezoelectric crystals for sound generation. Stimuli consisted of 0.1 msec square-wave clicks delivered at a rate of 10 Hz. White noise (60 dB) was delivered to mask the opposite ear.

Analog-to-digital conversion was accomplished by sampling each channel every 100 μs, and responses were recorded simultaneously from A_I-C_Z. All hardware was interfaced with a Nihon Kohden Inc., AEP Monitoring System for stimulus presentation, data acquisition, averaging and graphic display. A widely accepted method of wave V latency measurement was followed, based on peak identification (Chiappa et al., 1979). Measurements were made either from a clear peak or, when such

Fig 3. Photo of the BAEP experimental system.

was absent, from the linear midpoint of the nonpeaked wave. When wave Ⅴ was completely fused with wave Ⅳ, the latency was measured from the peak of the Ⅳ/Ⅴ complex. A pair of trials of A_I-C_Z recording was analyzed for absolute and interpeak latency and wave form.

Ⅲ. Results

The quantitative analysis was based on comparison of the changes between long-term cellularphone users-on/off and short-term cellularphone users. Figure 4~6 shows the spectral power densities at each electrode placement during the recording session under among non-field, field-on, and field-off conditions. Predominant α activity of the EEG could be observed in the frequency range around 10 Hz. This α activity is characteristic for the relaxed waking state under the eyes-closed condition. Although the time of investigation was short, and the number of subjects was small, some fluctuation of the spectral distribution of the α activity could be observed. There was no indication for an alteration of vigilance, i.e., we could not detect any decrease of EEG α and β activity, nor an increase in the $\varDelta$ and θ range.

No statistically significant differences among the three experimental conditions could be detected. The results of the evaluation of the mean spectral power densities at each electrode placement for all 20 subjects are summarized in Table 2. The

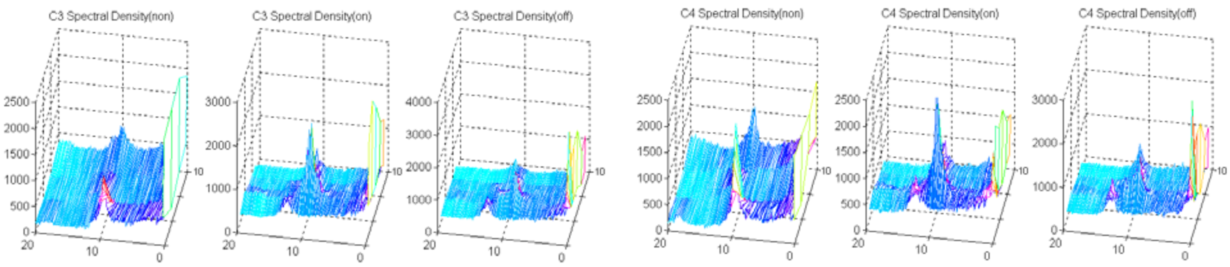

Fig 4. Comparison of spectral power densities in C3 and C4 during the recording session under among short-term use (left), long-term use-on (middle), and long-term use-off (right) conditions. Note) X axis : Hz, Y axis : spectral density, Z axis : number of sample.

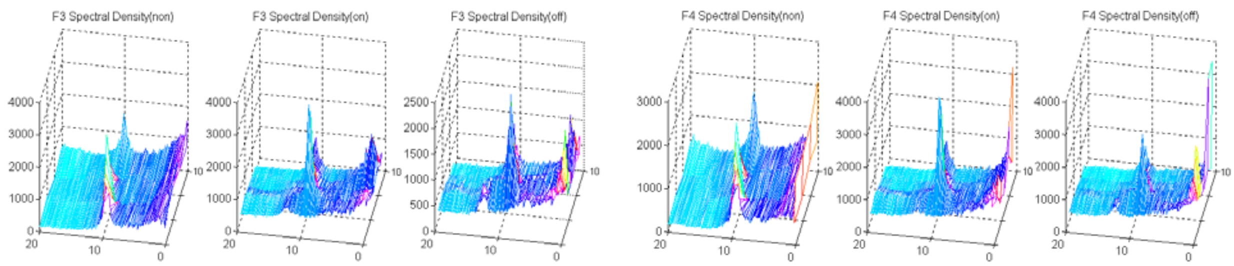

Fig 5. Comparison of spectral power densities in F3 and F4 during the recording session under among short-term use (left), long-term use-on (middle), and long-term use-off (right) conditions. Note) X axis : Hz, Y axis : spectral density, Z axis : number of sample.

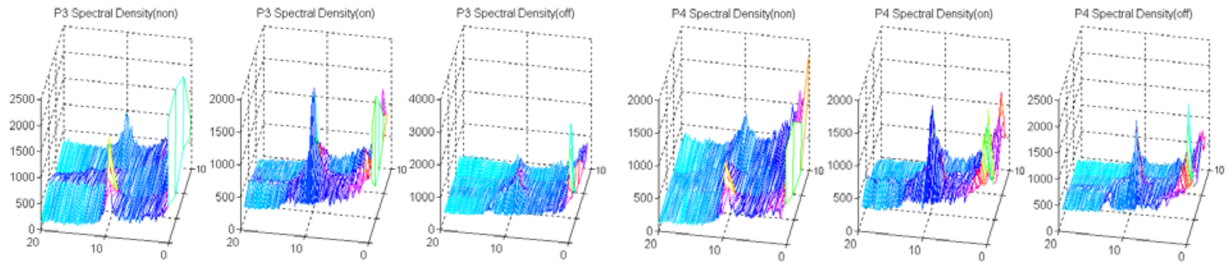

Fig 6. Comparison of spectral power densities in P3 and P4 during the recording session under among short-term use (left), long-term use-on (middle), and long-term use-off (right) conditions. Note) X axis : Hz, Y axis : spectral density, Z axis : number of sample.

Table 2. Mean spectral power densities(μ 2) and standard deviations for the EEG recording segment

Type of User \ Electrode Placement	F3	F4	C3	C4	P3	P4
Short-term User (N=10)	25.8±10.1	25.2± 7.1	12.0± 4.5	16.4± 5.5	20.7±5.3	15.1± 6.2
Long-term User-on (N=10)	26.4±15.1	28.6±18.4	14.1±10.1	15.8±10.9	18.5±8.8	21.8±12.1
Long-term User-off (N=10)	20.5± 8.9	25.4±12.8	14.5± 9.5	13.8± 9.0	20.3±8.1	18.6±10.5

mean values and standard deviations of the averaged spectral power densities are shown in units of μV^2 for the 20 subjects under the three experimental conditions. Statistical comparison of the data with and without exposure to the electromagnetic field revealed no significant difference for the EEG derivations ($P > .05$).

Table 3 shows the results of the absolute latency and interpeak latency for brainstem auditory evoked potential in each wave during the recording session for short-term users, long-term users-on, and long-term users-off conditions. The statistical comparison of the data between long-term users-on and long-term users-off exposure to the microwave revealed a significant difference for the resolution of short latency BAEP at wave V($P > .05$).

Ⅳ. Discussion

The amplitude of EEG potentials is much smaller than the voltage changes in single neuron. The surface EEG predominantly reflects the activity of cortical neurons close to the EEG electrode. Thus deep structures such as the hippocampus, thalamus, or brain stem do not contribute directly to the surface EEG. The EEG provides important indices for studying arousal, wakefulness, sleep and dreaming and for diagnosing epilepsy and coma.

EEG frequencies are conventionally subdivided into approximate frequency bands related to these three oscillation rhythms. In many studies, researchers suggest that the exact limits of the frequency band of α, β, δ, θ, and γ appear to be fuzzy. Kandel et al. classifies brain waves into α: 8 -13 Hz(relaxed 10 Hz, NREM sleep spindles 12 - 14 Hz); β: 13 - 30 Hz; and γ: 30 - 80 Hz (awake or REM 16 - 25 Hz); δ: 0.5 - 4 Hz (NREM 0.5 - 2 Hz); θ: 4-7 Hz (drowsiness)(Kan del et al., 2000).

Table 4 showed the effects of RF

Table 3. Absolute latency and interpeak latency in each wave among short-term users, long-term users-on, and long-term users-off condition (Mean±Standard Deviation)

(Unit : msec)

Type of wave \ Latency	ABSOLUTE LATENCY					INTERPEAK LATENCY		
Type of wave	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅰ-Ⅲ	Ⅲ-Ⅴ	Ⅰ-Ⅴ
Short-term users	1.7±0.2	3.1±0.2	4.1±0.3	5.2±0.3	5.8±0.4	2.4±0.1	1.8±0.2	4.1±0.2
Long-term users-on	1.7±0.2	2.9±0.1	4.0±0.1	5.1±0.1	5.9±0.2	2.3±0.1	1.9±0.2	4.2±0.2
Long-term users-off	1.6±0.2	2.9±0.1	3.9±0.1	5.1±0.1	5.8±0.2	2.3±0.1	1.9±0.2	4.2±0.2

Table 4. Effects of RF exposure on Electroencephalography (EEG)

EMF effect	Species	Frequency (MHz)	Modulation	Duration	Reference
No short term effects of digital mobile phone telephone on the awake closed eye EEG with special attention to the spectral power density of the α(8-13Hz) EEG	Human: 34 males (mean 27 years)	900 GSM mobile phone	217 Hz, pulse width 580 μs	3.5 min	Roschke & Mann, 1996
Effect with task-relevant target stimuli in the EEG band 18.75-31.25 Hz(β/γ/awake). No effect with irrelevant standard stimuli	Human: 13 healthy males 21-27 years	916.2	217 Hz pulse freq, pulse width 577 μs radiated power of aerial 2.8 W	Around 10 min	Eulitz et al., 1998
One-hour exposore to mobile phone RF EMF has no effect on auditory brainstem responses(ABRs) and distortion products otoemission(DPOE) recordings in the conditions of their protocol	10 men 10 women (20-30 years)	900	217 Hz GSM	60 min exposure	Thimonier et al., 1999
There was no main effect of E MF at any frequency band between the event related synchronous(ERS) and desynchronous responses(ERP) elicited by targets and non targets. reaction time or accuracy on a visual sequential letter task 'N-back'	24 Right handed adults M/F 20-30 (mean 24 years)	902 GSM	217 Hz, pulse width 577 μs, 0.25 W	Dimmed room, in chair, 30 min exp	Krause et al.,2000
MP RF may suppress the excessive sleepiness and improve performance while solving a monotonous cognitive task requiring sustained attention and vigilance	22 Narcolepsy-cataplexy pts mean 48 years	900 Motorola d 520 MP	217 Hz, pulse width 577 μs, 2.8 Hz, 0.25 W	45 min right ear	Jech et al.,2001

exposure on EEG. Eulitz et al. studied the interaction of cell phone pulsed MW exposure within the human brain(Eulitz et al., 1998) and they showed that the EMF alter distinct aspects of the brain's electrical response to acoustic stimuli. Krause et al. tested 24 right-handed young adults in a visual sequential letter □□N-back□□task under similar exposure conditions(Krause et al., 2000). There were no main effects of EMF at any frequency band in the visual N-back tasks. Jech et al. examined the effects of the MP(mobile phone) EMF on EEG and event-related potentials(ERP)(Jech et al., 2001).

There were no changes of the EEG recorded during the MP exposure, but they supposed the EMF of MP may suppress the excessive sleepiness and improve performance while solving a monotonous cognitive task requiring sustained attention and vigilance. We also studied and made a plan compared to reference papers. But, contrary to many experiments about GSM (global system for mobile communications) mobile, we use CDMA(code division multiple access) MP our study target.

In EEG and BAEP tests, we don't find out statistically significant changes. The reason may be drived from dosimetric uncertainties.

Hambin and Wood reviewed 14 articles that the effects of GSM MP RF energy on human brain activity and sleep variables. At this paper, they indicate that outcomes of the various studies have been inconsistent and comparison between individual studies is difficult(Hamblin & Wood, 2002).

It is very important to replicate these experiments for validating the results in other laboratories, but, most studies test only one dose with poor dosimetric controls and poor traceability and reflection of RF need to be assessed in exposure setups. Finally, to assess many negative and positive effects on the nervous system from electromagneic field of MP, more well-designed and delicate studies are need.

V. Conclusions

Public concern has increased about the possible health risks associated with exposure to microwaves emitting from cellularphones. In this paper, we presented results from electroencephalograms (EEG) and brainstem auditory evoked potential (BAEP) tests undertaken to examine the effects on the central nervous system from short-term and long-term cellularphone use.

Our study did not indicate any adverse effects on the activity of the human brain due to cellularphone use. There was no significant difference among short-term users, long-term user-on, and long-term users-off exposure to the microwave in the alpha frequency ranges (7.5-12.5 Hz) for the EEG derivation. There was only significant difference for the resolution of short latency BAEP at wave Ⅴ.

This study covered only the analysis of the short-term elevation of EEG asymmetry and BAEP latency after the onset of the microwave field. A more general assumption at present is that there is a probable interaction of MW fields with the EEG generators(Bise, 1978; Direnfeld, 1983). One of the possible key links in this effect can be calcium ion exchange in brain tissue(Adey, 1981). Indeed, it was found that the intracellular calmodulin level was changed by modulated MW fields(Katkov, 1992). It is possible to assume that this effect is based on different sensitivity of hemispheres to frequency of stimulus (Versage, 1985). The limitations of this study were a small number of volunteers and short exposure time to cellularphones for EEG and BAEP measurements.

Further study should provide information on the contribution of the various sources and the relationship between brain function and cellularphones use in individual differences.

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