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Effects of RF Fields Emitted from Smart Phones on Cardio-Respiratory Parameters: A Preliminary Provocation Study

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Abstract—**This paper describes an experimental setup for evaluating the physiological effects of radiofrequency (RF) emitted from a Wideband Code Division Multiple Access (WCDMA) module with a 24 dBm at 1950 MHz for specific absorption rate (SAR_{1g}) of 1.57 W/kg. This provocation study was executed in a double-blind study of two volunteer groups of 10 self-reported electromagnetic hypersensitivity (EHS) and 10 non-EHS subjects under both sham and real exposures in a randomly assigned and counter-balanced order. In the preliminary results, WCDMA RF exposure of 30 min did not have any effects on physiological changes in either group.**

I. Introduction

WITH the increasing usage of smart phones, social concerns have arisen about the possible effects of radio frequency (RF) emitted from smart phones on human health. The number of people with self-reported electromagnetic hypersensitivity (EHS) who complain of various subjective symptoms such as headache, insomnia, etc. has also increased. However, there have been a few provocation studies involving smart phones where physiological changes of RF radiation for EHS and non-EHS groups were investigated.

No widely accepted physiological mechanism exists to explain how exposure to smart phones might cause the symptoms reported by EHS. To test the role of electromagnetic fields (EMF) in causing physiological changes, it is very important to properly design the experimental study. Some studies were insufficient to determine whether exposure to EMF causes changes in any objectively measured end-points [1].

This paper describes an experimental setup to evaluate RF effects from Wideband Code Division Multiple Access (WCDMA) module with 24 dBm at 1950 MHz for the specific absorption rate (SAR_{1g}) of 1.57 W/kg. We designed a double-blind provocation study and gathered preliminary results from two volunteer groups: 10 subjects with self-reported EHS and 10 non-EHS subjects under both sham and real exposure in a randomly assigned and counter-balanced order.

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II. Materials And Methods

A. Experimental Setups

The lab was exclusively used for this experiment, and all other electrical devices were unplugged except our instruments in order to minimize background field levels. The background extremely low frequency (ELF) fields in the laboratory were measured to ensure that subjects were not influenced by them. The average ELF electric and magnetic fields were measured as 1.8 ± 0.0 V/m and 0.02 ± 0.01 μT, respectively, using an electric and magnetic field analyzer (EHP-50C, NARDA-STS, Milano, Italy). The RF field was measured at 0.05 ± 0.00 V/m with a frequency range from 1920 to 1980 MHz using a radiation meter (SRM 3000, Narda GmbH, Pfullingen, Germany).

In order to have better control over exposure, WCDMA modules with Qualcomm chipsets (baseband: MSM6290, RF: RFR6285, power management: PM6658) were used to generate WCDMA RF instead of a regular smart phone. It continuously transmitted at a mean output power of 24 dBm, which was measured using the E5515C Wireless Communication Test set (Agilent, Santa Clara, CA). The modules were inserted into a dummy phone [2]. According to the IEEE Standard, the position of the module was varied to meet the recommendations of 1.6 W/kg for general public SAR_{1g} [3]. The SAR measurements were made with a DASY 4 measurement system (SPEAG, Zurich, Switzerland). The flat phantom was filled with head tissue-equivalent liquid according to the Federal Communications Commission with a mass density of $\rho = 1000$ kg/m^3 [4]. The measured dielectric properties of the liquid were $\sigma = 1.41$ S/m, $\varepsilon_r = 39.7$ for the WCDMA frequency range. When the antenna of the module was located 67.5 mm from the ear reference point (ERP) of the dummy, the averaged peak spatial SAR_{1g} was measured to be

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1.57 W/kg at 1950 MHz in left cheek position [5]. The electric field was 6.9 V/m and power drift was -0.001 dB. SAR distribution is shown in Fig. 1.

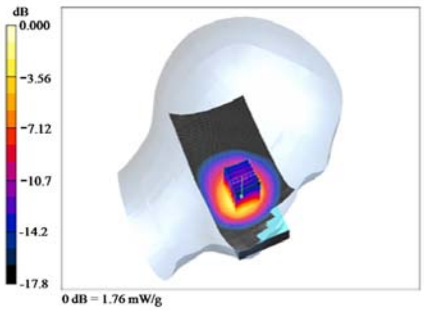

Fig. 1. SAR distribution on the left side of the phantom.

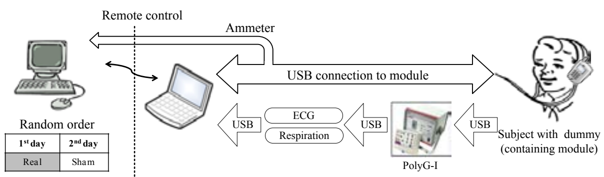

Fig. 2. Double-blind RF-RMF exposure system.

The module was connected to a portable laptop computer (X-note R500, LG electronics, Korea) via a 5 m USB cable and USB type ammeter for continuous exposure monitoring. The laptop computer was remotely controlled from another outside desktop to satisfy the double blind study (Fig. 2).

The dummy phone was attached to the subject's head using an earplug and headset to fix it on the ERP next to the cheek (Fig. 3) [6]. The phone was held at a distance of 3 mm from the ear using a piece of wood for insulation so that the subjects would not be aware of whether the phone was working through its battery-generated heat [7]. This was constructed only with plastic and rubber, but without any metal [6], [8].

B. Physiological Measurement

Electrocardiogram (ECG) and respiration were simultaneously collected during RF exposure using a computerized polygraph system (PolyG-I, Laxtha, Daejeon, Korea). The data were transferred to a nearby portable laptop computer and analyzed using an analysis software (Telescan and Complexity, Laxtha). Ag-AgCl electrodes (2223, 3M, St. Paul, MN) were placed on both arms and on the right leg to record ECG. We first obtained heart rate from ECG and then acquired heart rate variability (HRV) and the power spectrum of HRV. High-frequency power (HFP) reflects the effects on the parasympathetic nerve via respiratory sinus arrhythmia (RSA), whereas low-frequency power (LFP) reflects the effects on the sympathetic and parasympathetic nerves [9]. In this study LFP/HFP was used as an index for balance of autonomic nerve activity. Respiratory inductance plethysmography was used to measure respiration rate. A coiled band was worn around the subject's upper abdomen to measure inductance changes resulting from cross-sectional change.

C. Subjects

As Schröttner et al. reported, determination of EHS subjects is crucial to this provocation study [10], so we utilized the accredited EHS screening tool developed by Eltiti et al. [11]. They proposed that the following criteria be used to identify EHS individuals: (1) a total symptom score equal to or greater than 26 out of a maximum score of 228 (57 symptoms, each ranked from 0 for "not at all" to 4 for "a great deal"), (2) individuals who explicitly attribute their symptoms to exposure to EMF producing objects, and (3) individuals whose current symptoms cannot be explained by a pre-existing chronic illness.

Fig. 3. A subject with the dummy phone positioned next to her cheek.

The experiment was performed in a double-blind study with total of 20 subjects: 10 EHS (5 males and 5 females; 28.6 ± 7.5 years) and 10 non-EHS (5 males and 5 females; 27.8 ± 6.7 years). Twelve EHS and 10 non-EHS subjects were screened and 2 EHS subjects were excluded. One subject was excluded because of difficulty concentrating, and one subject was excluded due to hypnolepsy. None of the EHS and non-EHS subjects failed to attend the second day after attending the first day. No subjects had the experiment discontinued for any reason.

There were no statistical differences in age, male-female ratio, smoking, body mass index, mobile phone usage, computer usage/day, or TV viewing time/day between the two groups.

The subjects were advised not to take in caffeine, smoke or exercise and to sleep enough during the 24 hours before the experiment day in order to minimize confounding factors [7]. All subjects who were recruited by advertisements at the Yonsei University Hospital System (YUHS) were informed of the purpose and procedure of the experiment, and required to give a written consent to participate in the study. The Institutional Review Board (IRB) of the YUHS approved the protocol of this study (Project number: 1-2010-0030).

D. Procedures

The duration of each exposure session was 64 min as shown in Fig. 4. Before the experiment, subjects were made to rest in a sitting position for at least 10 min. Physiological data were collected for 5 min at four different stages: pre-test rest (stage I), after 11 min of exposure (stage II), after 27 min of exposure (stage III), and 11 min after exposure termination (stage IV).

At each stage, ECG and respiration were simultaneously measured for 5 min because of the long data requirement for HRV [12].

Room temperature was kept constant and recorded at 23.8 ± 0.6 ˚C throughout the experiment, because this factor could considerably affect outcomes. The relative humidity was 20.4 ± 4.5 %. After applying a paired t-test, there were no significant differences in temperature ($P = 0.069$) or humidity ($P = 0.102$) between the real and sham sessions. Each subject was remotely tested with both sham and real exposures in a randomly assigned and counter-balanced order.

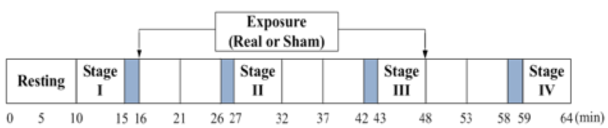

Fig. 4. Experimental procedure for measuring physiological parameters.

E. Data Analysis and Statistical Process

For HRV, the R-R intervals were acquired from the measured 5 min of ECG recording, and its power spectrum was obtained using software (TeleScan Ver.2.8, Laxtha). LFP/HFP was calculated with the HRV power spectrum to analyze changes in the autonomic nervous system. To minimize individual difference in LFP/HFP, the resting LFP/HFP was set at 100%.

A repeated measures two-way ANOVA test was performed to examine the physiological effects of exposure and duration with the WCDMA RF exposure on heart rate, respiration rate, and LFP/HFP for each group using SPSS software (SPSS 18, SPSS, Chicago, IL) with a significance level of 0.05. Bonferroni post-hoc test followed the two-way ANOVA to investigate any differences in LFP/HFP between each stage for each group.

III. Results

Table 1 shows the heart rate, respiration, and LFP/HFP in each stage during sham and real exposures for the EHS and non-EHS groups. The repeated measures two-way ANOVA test showed no significant difference in heart rate, respiration rate, or LFP/HFP for each stage, exposure and interaction in both groups except LFP/HFP for each stage in non-EHS group. Fig. 5 shows the relative changes in LFP/HFP for the EHS and non-EHS groups.

In the EHS group, there were no significant differences in heart rate ($P = 0.97$, 0.71, and 0.11), respiration rate ($P = 0.85$, 0.97, and 0.70), or LFP/HFP ($P = 0.28$, 0.50, and 0.20), between the real and sham exposures, between each stage, and interaction, respectively.

In the non-EHS group, there were no significant differences in heart rate ($P = 0.18$, 0.48, and 0.69) or respiration rate ($P = 0.94$, 0.54, and 0.87) between the real and sham exposures, between each stage, and interaction, respectively. LFP/HFP did not show significant differences between the real and sham exposures and interaction ($P = 0.76$ and 0.45), but showed significant differences between each stage ($P = 0.03$). By applying post-hoc test, there was a significant difference between stage I and II ($P = 0.04$) for the sham exposure, as shown in Fig 5. However, this significant difference obviously did not result from RF exposure, but was caused by other factors.

Table 1. Heart rate, respiration, and LFP/HFP in each stage during sham and real exposure for the EHS (n = 10) and non-EHS (n = 10) groups. (Mean ± standard deviation)

		Sham				Real			
		I	II	III	IV	I	II	III	IV
HR (bpm)	EHS	78±13	78±13	79±13	79±12	79±13	79±12	78±11	78±11
	non-EHS	84±18	86±33	82±22	81±16	76±9	76±8	75±6	75±6
Resp. (bpm)	EHS	18±4	18±3	18±3	18±3	18±4	18±4	18±4	18±4
	non-EHS	19±3	19±2	19±3	18±2	19±5	19±5	18±4	19±4
LFP/HFP (%)	EHS	100±0	107±56	90±40	113±79	100±0	120±64	178±166	126±82
	non-EHS	100±0	140±49	135±53	137±55	100±0	129±63	175±147	142±93

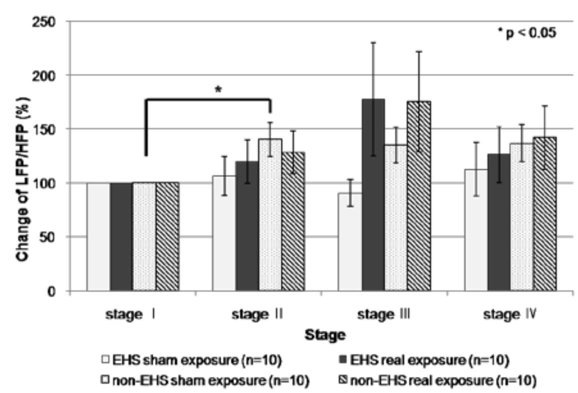

Fig. 5. Relative changes (%) in LFP/HFP in each stage with sham and real exposures for the EHS and non-EHS groups. The error bar indicates standard errors.

IV. Discussion and Conclusion

This double-blind experimental setup made it possible to investigate the effects of smart phones on physiological changes. We also utilized the accredited EHS screening tool for objective grouping. Neither the EHS nor the non-EHS group showed significant differences in heart rate or respiration rate between the real and sham exposures or between each stage. In the case of LFP/HFP, however, there was a significant difference between some stages during the sham session in the non-EHS group. We assume that this was caused by sleep deprivation, which can cause increases in LFP and LFP/HFP [7], [13]. According to our preliminary results, WCDMA RF exposure of 30 min did not have any effects on heart rate, respiration rate, or HRV in either group.

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