Effects of RF Exposure of Teenagers and Adults by CDMA Cellular Phones

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Many cellular phone provocation studies have been conducted since the question of increased health risk from extended usage of cellular phones became a social issue. Internationally, most studies have been conducted regarding the effects of GSM cellular phones on blood pressure and heart rate of adult volunteers. On the other hand, very few provocation studies have been conducted regarding the physiological effects of CDMA phones on teenagers. In this study, two volunteer groups consisting of 21 teenagers and 21 adults were exposed to 300 mW of radio frequency (RF) electromagnetic field emitted by a CDMA cellular phone for half an hour. Physiological parameters such as systolic and diastolic blood pressures, heart rate, respiration rate, and skin resistance were simultaneously measured. All the parameters for both groups were unaffected during the exposure except for decreased skin resistance of the teenager group (P < .0001). For the regrouped 23 male and 19 female subjects, all the parameters for both groups were unaffected during the exposure except for decreased skin resistance of the male subjects (P = .0026). Those resistances at 10 min after the terminated exposure returned to the resistances at rest regardless of the different groups of age and sex. Bioelectromagnetics 27:509–514, 2006. © 2006 Wiley-Liss, Inc.

Key words: provocation; heart rate; blood pressure; skin resistance; respiration rate; human exposure

INTRODUCTION

In recent years, many social and health issues have been raised regarding the extensive usage of cellular phones among teenagers. Various subjective symptoms have been reported in European countries including Sweden and Norway. Reports indicated that NMT (analog) phone users were affected more by radio frequency (RF) fields emitted by cellular phones than GSM (digital) phone users [Oftedal et al., 2000]. In 2002, the English and Australian governments suggested reducing the usage of cellular phones due to possible harmful effects on teenagers’ health, especially during their growth period [Maisch, 2003]. The majority of the cellular phone users were using GSM phones; thus, various studies were conducted on subjective symptoms attributed to GSM phones [Oftedal et al., 2000; Koivisto et al., 2001; Hietanen et al., 2002]; physiological change of blood pressure and heart rate [Braune et al., 1998; Tahvanainen et al., 2004], neurophysiological change [Freude et al., 1998], and cognitive functions [Preece et al., 1999; Edelstyn and Oldershaw, 2001].

Visual reaction time was prolonged and the scores of short term memory tests of children were lower in some high intensity microwave exposure groups [Chiang et al., 1989]. Kolodynski and Kolodynska [1996] found that children living in front of a pulsed radar station had less-well developed memory and attention, and their reaction time was slower. Although these two studies did not investigate physiological effects of cellular phones, it showed that microwave electromagnetic fields (EMF) could affect children’s health. The World Health Organization (WHO [2003]) Children’s EMF Research Agenda indicated that the influence of RF exposure on sleep, headache, and memory loss among teenagers required high priority investigation [http://www.who.int/emf].

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In Korea, a different digital technology, CDMA, has been used. It has a relatively weak power output (max. power 300 mW) compared to the GSM phones used in the United States and Europe. As provocation studies regarding the effects of CDMA phones on teenagers are few, such studies are warranted. In this study, changes in heart rate, respiration rate, and skin resistance were simultaneously measured by our constructed system without pain or discomfort. The above parameters have been routinely measured in lie detectors. Systolic and diastolic pressures were measured using a commercial non-invasive automatic blood pressure (NIBP) measurement system. Using statistical analysis, significant changes of blood pressure, heart rate, respiration rate, and skin resistance of each group with varying exposure times were investigated for real and sham exposures.

MATERIALS AND METHODS

Physiological Measurements

During the sham and real exposures by CDMA cellular phones, heart rate, respiratory rate, skin resistance, and blood pressures were measured. Measurements of the heart rate and the digital blood flow waveform were collected by applying a photoplethysmography (PPG) sensor (DS-100, Nellcor, Pleasanton, CA, USA) to the index finger (Fig. 1A). Skin resistance decreases due to increased sweat secretion when sympathetic nerves are stimulated [Critchley, 2002]. The skin resistance was measured using mesh type electrodes (3M, St. Paul, MN, USA) attached to the left middle and fourth fingers as shown in Figure 1A. Respiratory inductance plethysmography (RIP) was utilized to measure the respiration rate by applying a coiled band built for this study on the subject’s abdomen to measure the inductance changes resulting from cross-sectional change, as shown in Figure 1B. Amplifier gain adjustment was occasionally needed to avoid saturation.

A NIBP monitor (T4, OMRON, Tokyo, Japan) was used to measure systolic and diastolic blood pressures. The cuff was applied on the subject’s right upper arm at approximately the same height as the position of the subject’s heart. The blood pressures were measured three times every minute and averaged (Figs. 2 and 3). A CDMA phone with a SAR of 1.6 W/kg and a transmitting frequency range of 824.64–848.37 MHz was used (SCH-V3000, Samsung Electronics, Suwon, Korea). The carrier frequency used in this experiment was 835 MHz. The phone was set to test mode which radiated continuous clipped sine waves with a maximal transmission power of 300 mW.

A conventional headphone was modified to install a folder-type cellular phone on the left side of the head as shown in Figure 1C. The lower part of the cellular phone with buttons was wrapped up with 5 mm thick insulating material in order for the subject to be unaware of whether the phone was working by feeling the generated heat. The insulating material of the battery side was cut out to be open in order to dissipate heat generated from the battery. As a consequence, the upper part of the phone with the headphone had the same configuration, and thus the same spacing between its upper part and the ear as the phone alone. Its lower part with insulation had 5 mm more spacing from the user’s chin than the phone without it.

Figure 2 shows a complete experiment setup. One worker measured the subject’s heart rate, respiration, and skin resistance. Data was taken by a three channel measurement system and saved to a notebook PC (SV20, Samsung Electronics) using DAQpad (6020E, National Instruments, Austin, TX, USA). The data was taken by a three channel measurement system and saved to a notebook PC (SV20, Samsung Electronics) using DAQpad (6020E, National Instruments, Austin, TX, USA). The data was taken by a three channel measurement system and saved to a notebook PC (SV20, Samsung Electronics) using DAQpad (6020E, National Instruments, Austin, TX, USA).
acquisition program was developed using LabVIEW 6.1 (National Instruments).

Subjects

Twenty-one teenagers (12 males and 9 females; 15.9 ± 2.3 years) and 21 adults (11 males and 10 females; 30.9 ± 5.6 years) participated in this study. The teenager group included high school students and the adult group included graduate students and older subjects. All volunteers were informed about the purpose and procedure of the study and asked written consent. In addition, parental consent was obtained for the teenagers. Forty two subjects were regrouped to 23 male (20.2 ± 4.8 years) and 19 female (21.6 ± 8.3 years) subjects in order to see any discrepancy in the physiological parameters between the sexes. The Yonsei Medical Research Ethics Committee reviewed the full protocol with co-opted advice from pediatric consultants.

Experimental Setups and Procedures

The experimental setup was as follows: Real and sham exposures were performed in a double blind test to minimize experimental bias. One worker only controlled the power of the phone and the other acquired and analyzed the data. Neither the worker acquiring the data nor subjects knew whether the cellular phone worked or not. Prior to the experiment, subjects rested on the experimental bed in supine position for 30 min. Because having an actual conversation over the phone may affect the subject’s mental condition or physiological function, the experiment was performed without any conversation. Since output power decreases without actual conversation, the cellular phone used in this experiment was set at an maximum output power of 300 mW in the test mode.

The experimental procedure was as follows: The experiment was divided into real and sham exposures. The duration of each exposure lasted for half an hour from

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<tr>
<td>10 min</td>
<td>15 min</td>
<td>11 min</td>
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Fig. 2. Photo of experimental setup.

Fig. 3. Experimental procedure for measuring physiological parameters during RF exposure by a CDMA cellular phone.
start to finish, as shown in Figure 3. Data was collected at four different stages with the headset on the subject’s head: after a 10 min rest, after 15 and 30 min exposure to the RF field, and 10 min after exposure termination. At each stage, PPG, respiration, and skin resistance were measured during the first minute. Blood pressure was measured three times on 1 min intervals. In order to avoid interference with the previous real exposures, the sham exposures were performed first. The exposure sequence was not randomized because the preceding real exposures might produce effect longer than a day, resulting in the different physiological conditions between the real and the sham exposures. Between the sham and real exposures, the subject took a 30 min break. The subjects were asked to report any subjective symptoms such as dizziness. Temperature and humidity were recorded and kept throughout the experiment, since these factors could affect the results.

**Data Analysis**

In Figure 4, each pulse on the PPG waveform represents the cardiac pulse. Data was selected where it showed the most stable pulses for 30 s within a 60 s recording. Heart rate per minute was obtained by dividing the number of pulses by the selected time in seconds and multiplying by 60. In the RIP waveform, the positive direction of the y axis represents inhalation, while the negative direction represents exhalation. RIP data was also selected for 30 s and the respiration rate was obtained. Skin resistance was measured in voltage on the GSR waveform. Data was collected for 1 min and averaged to analyze the change in skin resistance. A repeated two-way ANOVA test was performed using SPSS software (SPSS 10, SPSS, Inc., Chicago, IL, USA), with the significance level of .05 in order to investigate the effects of exposure and duration for each group by a CDMA cellular phone. Bonferroni multiple comparison method was performed for further analysis.

**RESULTS**

**Teenager and Adult Groups**

Results of the repeated two-way ANOVA test did not show any effects of the RF exposure and exposure duration on all the physiological parameters measured for the adult group. There were no statistically significant differences between the real and sham exposures in heart rate ($P = .413$), respiration rate ($P = .598$), systolic ($P = .575$) and diastolic blood pressures ($P = .057$), or skin resistance ($P = .418$). There were also no statistically significant differences in heart rate ($P = .996$), respiration rate ($P = .530$), systolic ($P = .988$) and diastolic blood pressures ($P = .661$), or skin resistance ($P = .438$) between the exposure duration.

![Fig. 4. Example of measured PPG, RIP, and GSR signals.](image)
The results of the teenage group indicated that there were no statistically significant differences between real and sham exposures in heart rate \( (P = .614) \), respiration rate \( (P = .672) \), systolic \( (P = .852) \), and diastolic blood pressure \( (P = .168) \). However, the changes in skin resistance were all significant, for the real exposure \( (P < .0001) \), exposure duration \( (P < .0001) \), and interaction between exposure and duration \( (P = .0048) \), respectively. By applying the Bonferroni multiple comparison test, the skin resistances at rest and 15 min \( (P = .0211) \) and 30 min exposures \( (P < .0001) \) were significantly different. The resistances for the real exposure at rest and 15 min \( (P = .0091) \) and 30 min \( (P < .0001) \) were significantly different.

To analyze the relative change of skin resistance, the resting resistance values of real and sham exposures were set at 100% as shown in Figure 5. The resistance returned to the initial resting resistance \( (P = .0574) \) 10 min after the end of the real exposure. Our study supports the WHO contention that youths may be more susceptible or sensitive than adults to effects from mobile phone exposures [http://www.who.int].

**Male and Female Groups**

Results of the repeated two-way ANOVA test did not show any effects of the RF exposure and exposure duration on all the physiological parameters measured for the female group. There were no statistically significant differences between the real and sham exposures in heart rate \( (P = .620) \), respiration rate \( (P = .979) \), systolic \( (P = .667) \) and diastolic blood pressure \( (P = .820) \), or skin resistance \( (P = .100) \) for the female group. There were also no statistically significant differences in heart rate \( (P = .980) \), respiration rate \( (P = .991) \), systolic \( (P = .967) \) and diastolic blood pressures \( (P = .949) \), or skin resistance \( (P = .149) \) between the exposure duration.

The results of the male group showed that there were no statistically significant differences between real and sham exposures in heart rate \( (P = .515) \), respiration rate \( (P = .916) \), systolic \( (P = .729) \), and diastolic blood pressures \( (P = .112) \). However, the changes in skin resistance were all significant, for the real exposure \( (P = .0026) \), exposure duration \( (P = .0025) \), and interaction \( (P = .01) \) between exposure and duration, respectively. By applying Bonferroni multiple comparison test, the skin resistances at rest and 30 min exposure were significantly different \( (P = .0011) \). The resistances for real exposure at rest and 30 min are significantly different \( (P < .0001) \) as shown in Figure 6. However, the resistance returned to the initial resting resistance \( (P = .5097) \) 10 min after the end of the real exposure.

**DISCUSSION**

In the teenage group, physiological parameters such as heart rate, respiration rate, and systolic and diastolic blood pressures did not show any significant changes regardless of real or sham exposure, and exposure duration. But the skin resistance decreased significantly under real exposures. This decrease indicates that RF electromagnetic fields might stimulate teenager’s autonomic nervous system, resulting in sweat secretion. Ten minutes after the real exposure termination, the skin resistance of the teenager group returned to the initial resting value. On the contrary, there were no significant changes in heart rate, respiration rate, blood pressures, or skin resistance in
the adult group, regardless of the real or sham exposure and exposure duration to a CDMA cellular phone.

It was surprising to find that there was significant decrease in skin resistance by RF exposure from cellular phone for the male group only, while there were no effects of the RF exposure and exposure duration on all the tested physiological parameters for the female group. This finding warrants for further verification.

Hietanen et al. [2002] reported changes in heart rate and blood pressure of adults in relation to the RF exposure emitting from 900 MHz NMT, 900 MHz GSM, and 1800 MHz GSM phones. Braune et al. [1998] reported the effects of RF EMF emitted by a 900 MHz GSM cellular phone on sympathetic efferent activity in adults by observing heart rate, vasoconstriction, and blood pressure. However, Tahvanainen et al. [2004] reported no change in blood pressure or heart rate of adults after the exposure to 900 MHz and 1800 MHz GSM cellular phones for 35 min. Furthermore, Koivisto et al. [2001] found that there existed no correlation between exposure to 900 MHz cellular phones and the subjective symptoms complained by users.

Previous studies of the physiological effects of GSM cellular phones have various results depending upon the method and condition of the experiments. However, the results obtained from these studies concern only GSM cellular phones and focus on adult groups. Consequently, direct comparison of their results to those of this study is not appropriate. Nevertheless, even with differences in transmission method and power from that of a GSM cellular phone, the adult group in this study was hardly influenced by the CDMA cellular phone exposure.

On the other hand, the teenage and male groups in this study showed decreased skin resistance with the increased spacing of 5 mm on the lower phone folder segment compared to the conventional conversational position. It is true that even a millimeter spacing distance can make a big decrease in SAR. However, the decreased skin resistances of the teenage and the male groups are still valid for the output power less than 300 mW that is more similar to the conventional usage. These findings could indicate the possibility of increased sensitivity of the teenage and the male groups to an RF field. In order to indisputably confirm the effects of the RF field generated by the CDMA cellular phone on the human body, further studies should examine an extended time of exposure and measure more physiological changes under diverse conditions. According to the WHO Children’s EMF Research Agenda, the effects of cellular phones on cognition, memory, fatigue, headache, overreaction, hormonal change, and sleeping disorders in teenagers should be studied.

In conclusion, this provocation study found a statistically significant association between mobile phone exposure and decreased skin resistances in teenagers, lending support to the recommendation by the WHO [2003] Children’s EMF Research Agenda that assessment of children’s sensitivity to RF should be a high priority agenda item. The replication studies are warranted to confirm the results of this study that skin resistance is sensitive to RF radiation by cellular phone, and teenagers and males are sensitive to it.

REFERENCES


