Origins of Electromagnetic Hypersensitivity to 60 Hz Magnetic Fields: A Provocation Study

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With increasing electrical device usage, social concerns about the possible effects of 60 Hz electromagnetic fields on human health have increased. The number of people with self-attributed electromagnetic hypersensitivity (EHS) who complain of various subjective symptoms such as headache and insomnia has also increased. However, it is unclear whether EHS results from physiological or other origins. In this double-blinded study, we simultaneously investigated physiological changes (heart rate, respiration rate, and heart rate variability), subjective symptoms, and perception of the magnetic field to assess origins of the subjective symptoms. Two volunteer groups of 15 self-reported EHS and 16 non-EHS individuals were tested with exposure to sham and real (60 Hz, 12.5 μT) magnetic fields for 30 min. Magnetic field exposure did not have any effects on physiological parameters or eight subjective symptoms in either group. There was also no evidence that the EHS group perceived the magnetic field better than the non-EHS group. In conclusion, the subjective symptoms did not result from the 60 Hz, 12.5 μT magnetic field exposures but from other non-physiological factors. Bioelectromagnetics

Key words: 60 Hz; hypersensitivity; physiological changes; subjective symptoms; perception

INTRODUCTION

As the use of electrical devices increases, there are growing social concerns about the biological effects of electromagnetic fields (EMFs). In our daily lives, the most common energy source is 50 or 60 Hz in the extremely low frequency (ELF) range. Accordingly, the number of people who complain of various symptoms such as headache, exhaustion, and insomnia is on the rise. Complaining of symptoms attributed to EMFs is called electromagnetic hypersensitivity (EHS) or self-attributed EHS. It has been reported that the EHS population accounts for 1.5% of the total population in Sweden, 3.2% in California (USA) and 5% in Switzerland [Hillert et al., 2002; Levallois et al., 2002; Schreier et al., 2003].

Röösli et al. [2004] reported that sleep disorder (58%), headache (41%), nervousness or distress (19%), fatigue (18%), and concentration difficulties (16%) were the most common complaints in Switzerland. This implies that EHS could not only cause the deterioration in the quality of individual patient’s lives, but also increase social expenses for health care. Eltiti et al. [2007] categorized EHS by evaluating subjective judgment. The diagnostic method for EHS is still not clear, and the origin of EHS has not been identified [Leitgeb and Schröttner, 2003; Rubin et al., 2005; Eltiti et al., 2007]. Therefore, a comprehensive study is necessary to understand whether EHS is caused by real EMF perception or by psychological factors.

Andersson et al. [1996] reported that none of the psycho-physiological measures or subjective reactions to a provocation test showed any significant difference between the EHS and non-EHS groups. Sandström et al. [2003] compared EHS to non-EHS subjects and found different patterns in heart rate...
variability (HRV) between the groups, but no difference between the groups with regard to magnetic field exposure (monitored during 24 h). Rubin et al. [2005] concluded that EHS was not related to the ability to perceive EMF after analyzing 31 research articles on EHS. In their other recent review, they reported that there was no evidence for a connection between EMFs and symptoms [Rubin et al., 2010]. Lyskov et al. [2001] reported that there was a difference in the baseline values of heart rate and electrodermal activity between EHS and non-EHS individuals, but that there was no effect from the low-level 60 Hz magnetic field exposure. Only a few provocation studies, including Hamnerius et al. [1993], Lonne-Rahm et al. [2000], Furubayashi et al. [2009], and Nam et al. [2009], simultaneously examined aspects of the factors of subjective symptoms, EMF perception, and physiological change. These three factors need to be simultaneously investigated to determine reliable origins of EHS.

In this double-blind study, we measured heart and respiration rates for both the EHS and non-EHS groups, and then obtained the HRV using the measured heart rate. In addition, the subjects were asked to describe subjective symptoms and EMF perception during pre-exposure, sham and real exposures, and post-exposure. The aim of this study was to test whether 60 Hz magnetic fields influence heart rate, respiration rate and HRV, or give rise to subjective symptoms in EHS and non-EHS subjects. Further, we also compared EHS and non-EHS subjects’ ability to perceive exposure to a magnetic field to determine the origin of the subjective symptoms experienced by individuals with EHS.

MATERIALS AND METHODS

Subjects

Only subjects who attributed their symptoms to appliances and/or high voltage transmission lines, but not to mobile phones alone, were recruited as EHS individuals through advertisement in the Yonsei University Health System (YUHS) in Seoul, Korea. Because the determination of EHS subjects is very crucial to this study, as Schröttner et al. [2007] reported, we used the accredited EHS screening tool developed by Eltiti et al. [2007]. They proposed the following criteria to identify EHS individuals: (1) a total symptom score greater than or equal to 26 (out of a maximum score of 228) of 57 symptoms assigned 0 for “not at all” to 4 for “a great deal,” (2) individuals who explicitly attribute their symptoms to exposure to ELF EMF-producing objects, and (3) individuals whose current symptoms cannot be explained by a pre-existing chronic illness.

In addition to the screening tool above, only healthy subjects without any diseases and not on medications were chosen for EHS and non-EHS subjects. However, there were no medical check-ups for the selected subjects. They were informed of the purpose and procedure of the experiment, and were asked to give a written informed consent before joining the study. The Institutional Review Board of the YUHS approved the protocol of this study (project number: 4-2008-0152).

A total of 31 subjects participated in this experiment: 15 EHS subjects (10 males and 5 females; 26.2 ± 2.7 years) and 16 non-EHS subjects (11 males and 5 females; 25.6 ± 3.1 years). There were no statistically significant differences in age (P = 0.586), male to female ratio (P = 1.000), smoking status (P = 1.000), body mass index (P = 0.572), cellular phone usage period (P = 0.654), computer usage per day (P = 0.682), or TV viewing time per day (P = 0.892) between the two groups.

Physiological Measurement

Figure 1 shows the complete experimental setup used to evaluate EHS and the 60 Hz magnetic field exposure system. The subjects’ heart rate, respiration rate and HRV were obtained with a computerized polygraph (PolyG-I, Laxtha, Daejeon, Korea), with a sampling frequency of 512 Hz. The data were transferred to a nearby Compaq notebook computer (NX6120, Hewlett Packard, Palo Alto, CA) and analyzed using Telescan 0.9 (Laxtha; data acquisition...
software) and Complexity software (Laxtha; data analysis software). The polygraph recorded the electrocardiogram (ECG) through Ag-AgCl electrodes (2223, 3M, St. Paul, MN) placed on both arms and the right leg of participants, as shown in Figure 2.

We first obtained heart rates from the ECG and then acquired HRV and the power spectrum of HRV. High-frequency power (HFP) reflects the effects on the parasympathetic nervous system such as respiratory sinus arrhythmia (RSA), whereas low-frequency power (LFP) reflects the effects on the sympathetic and parasympathetic nervous systems [Parazzini et al., 2007]. In this study, LFP/HFP was used as an index for the balance of the autonomic nervous system. Respiratory inductance plethysmography with an excitation frequency of 3 MHz was used to measure respiration rates. A coiled band was worn around the subject's upper abdomen to measure inductance changes resulting from cross-sectional change, as shown in Figure 2.

Subjective Symptoms and Perception of EMF

Symptoms such as headache, insomnia, and fatigue cannot be confirmed by measuring physiological changes such as heart rate, respiration, and HRV alone. In this study, eight subjective symptoms (throbbing, itching, warmth, fatigue, headache, dizziness, nausea, and palpitations) were evaluated through verbal surveys, which were graded on a 4-point scale (ranging 1–4) established by Koivisto et al. [2001]. In addition, perception of 60 Hz magnetic field exposure was investigated every 5 min during the entire session as shown by an “x” or “o” in Figure 3. Subjects were asked to answer the question “Do you believe that you are exposed right now?” nine times during each session. Percentages of those who believed they were being exposed were calculated for pre-exposure, exposure, and post-exposure periods.

Experimental Setups and Procedures

The lab was used exclusively for this experiment, and all other electrical devices were unplugged except for the instruments used to minimize background field levels. The background ELF fields in the laboratory were measured to ensure that subjects were not influenced by these fields. The average ELF electric and magnetic fields were measured at 0.8 ± 0.0 V/m and 0.03 ± 0.00 μT, respectively, using an electric and magnetic field analyzer (EHP-50C, NARDA-STS, Milan, Italy).

The magnetic field generator consisted of an arbitrary function generator (33220A, Agilent, Santa Clara, CA) and solenoid coils with 2000 turns, with a radius of 20 cm, height of 20 cm, and coil thickness of 0.7 mm (Fig. 1). The output of the function generator was controlled using LabVIEW 2009 software (National Instruments, Austin, TX). The solenoid coil was placed 20 cm higher than the top of the participant’s head and was covered with fabric to conceal it from the subject (Fig. 2). The distance from the bottom of the coil to the top of the subject’s head was maintained at 20 cm by adjusting the chair height to expose the top of the head at 12.5 μT. We selected 12.5 μT because it was the strongest magnetic field measured directly under most transmission lines in South Korea according to Korea Electric Power.

The subjects were told to avoid caffeine, tobacco, alcohol and exercise, and were advised to get adequate sleep 24 h before the experiment day to minimize confounding factors. No information was given to the participants except that they would be asked about symptoms and EMF perception at the beginning of the first experimental day. Sham and...
real exposures were conducted double blind to minimize any test bias resulting from a subject and an experimenter recognizing the operational state of the magnetic field generator. Each subject was tested for sham exposure on the first day and real exposure on the second day, or vice versa. No matter which came first, sham or real exposure, the second session was always given at approximately the same time of the day as the first session in order to maintain the subject’s physiological rhythm. The order of sham and real exposure for a subject was randomly assigned and counterbalanced using our automatic exposure control program and LabVIEW 2009 software to minimize experimental bias. Eight subjects in the EHS group and eight in the non-EHS group received sham exposure first.

The duration of each session was 64 min, as shown in Figure 3. Before the experiment, subjects were told 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 [Marek et al., 1996]. The four shaded areas in Figure 3 are periods during which they were questioned regarding the eight symptoms, and each period lasted approximately 1 min.

Questions regarding EMF perception were asked every 5 min, starting just before exposure began until 10 min after exposure ceased. The “o” and “x” indicate the time when EMF perception was inquired about during the periods of exposure (real or sham) and non-exposure, respectively. During real exposure sessions, the EMF perception question was asked five times during exposure and four times during non-exposure. During sham exposure sessions, it was asked nine times during non-exposure. The total number of inquiries was 155 (5 \times 31) during exposure and 403 (13 \times 31) during non-exposure, where 31 (15 + 16) was the total number of subjects.

Room temperature was recorded and maintained at 23.9 ± 1.1 °C throughout the experiment because this factor could considerably affect outcomes. The relative humidity was 43.9 ± 10.1%. After applying a paired t-test, there were no significant differences in temperature (P = 0.781) and humidity (P = 0.968) between the real and sham sessions.

Data Analysis

For HRV, the R-R intervals were acquired from the 5 min ECG recordings, and the power spectrum was obtained using TeleScan Ver.2.8 software (Laxtha). The LFP/HFP ratio was calculated from the HRV power spectrum to analyze changes in the autonomic nervous system. To analyze the relative changes in LFP/HFP, the LFP/HFP in stage I for real and sham exposures was set at 100%.

A repeated two-way analysis of variance (ANOVA) test was performed using SPSS software (SPSS 10, SPSS, Chicago, IL) with a significance level of 0.05 to investigate any significant differences in heart rate, respiration rate, and LFP/HFP with exposure and stage for EHS and non-EHS groups. A repeated two-way ANOVA was also performed to investigate any significant differences in heart rate, respiration rate, and LFP/HFP with group and stage for sham and real exposures.

Since subjective symptoms were ordered and paired data, the non-parametric Wilcoxon signed-rank test was used for analysis. A total of 64 P-values (4 stages \times 8 symptoms \times 2 groups) were obtained from the real and sham exposures for the four stages of the eight symptoms in both groups.

There were two exposure sessions consisting of sham and real for each participant, and nine perception inquiries for each session, as shown in Figure 3. For each session, there was one inquiry in the pre-exposure stage, five inquiries in sham or real exposure stage, and three inquiries in the post-exposure stage. In both groups, the percentage of those who believed they were being exposed was obtained and compared for significant differences between the real and sham sessions using the Wilcoxon signed-rank test. The pre-exposure period of the sham sessions was compared with those of the real sessions to test whether the condition of the subjects had been the same before the sham and real exposures. The sham exposure period was compared with the real exposure period to test whether the subjects could detect the fields. The post-exposure period after sham exposure was compared with the post-exposure period after real exposure to test whether the exposure influenced the belief of being exposed in the post-exposure period. The Mann–Whitney U-test was applied to examine significant differences in the percentages of those who believed they were being exposed between the EHS and non-EHS groups for exposure and non-exposure.

RESULTS

EHS and Non-EHS Groups

Twenty EHS subjects were screened and five subjects were excluded. One subject was excluded
because of isolated EHS to cellular phones, and one subject was excluded due to hypnolepsy. The other three excluded participants did not attend the first experimental day. None of the EHS subjects and one non-EHS subject failed to attend the second day after attending the first day. No subjects had the experiment discontinued for any reason.

The symptom scores for the EHS and non-EHS groups using Eltiti’s scale were 32.5 ± 12.2 and 5.9 ± 5.3 (mean ± SD), respectively. The number of symptoms for the EHS and non-EHS groups were 33 ± 14 (range 11–57) and 5 ± 4 (range 0–12), respectively. The most typical symptoms reported in the EHS group were fatigue (n = 15), difficulty in concentrating (n = 14), vertigo (n = 14), foggy thinking (n = 14), heaviness in the head (n = 14), blurry vision (n = 13), difficulty in focusing attention (n = 13), digestive problem (n = 13), and ringing in the ears (n = 13) among 57 subjective symptoms (multiple answers allowed). Among the EHS subjects, the most common sources they reported as causing their symptoms were personal computer (n = 11), TV (n = 9), microwave oven (n = 2), electric mattress (n = 1), and fluorescent light (n = 1; multiple answers allowed). If a non-EHS subject attributed any symptoms to EMF exposure, the subject was excluded from the non-EHS group.

**Physiological Variables**

A repeated two-way ANOVA test showed no significant differences in heart rate, respiration rate, or LFP/HFP for stage and exposure in either group except LFP/HFP for stage. Therefore, the Bonferroni post hoc test was done after the two-way ANOVA to investigate any difference in LFP/HFP between stages for each group.

For the non-EHS group, there were no significant differences in heart rate (P = 0.064 and 0.278), respiration rate (P = 0.245 and 0.200), or LFP/HFP (P = 0.816 and 0.212), between real and sham exposures and between stages, respectively. Figure 4A shows the relative changes in LFP/HFP for the non-EHS group. For the EHS group, there were also no significant differences in heart rate (P = 0.780 and 0.922) or respiration rate (P = 0.128 and 0.293) between real and sham exposures and between stages, respectively. In Figure 4B, LFP/HFP did not show a significant difference between real and sham exposures (P = 0.782), but did show a significant difference between the stages (P = 0.001).

A repeated two-way ANOVA was also performed to investigate any significant differences in heart rate, respiration rate, and LFP/HFP between EHS and non-EHS groups. There were no significant differences in heart rate between the stages (P = 0.276 and 0.453) and between groups (P = 0.707 and 0.294) for the sham and real exposures, respectively. There were also no significant differences in respiration rate between the stages (P = 0.061 and 0.976) and between groups (P = 0.136 and 0.434) for the sham and real exposures, respectively. However, there was a significant difference in LFP/HFP between stages (P = 0.008) but not between groups (P = 0.057) for the sham exposure. For the real exposure there were significant differences in LFP/HFP between stages (P < 0.001) and between groups (P = 0.002), with a significant interaction between stage and group (P = 0.003). Because of the significant level of the interaction, the significant differences in stage and group were not confirmed for the real exposure.
Subjective Symptoms

The EHS group showed no significant differences in any of the four stages between the sham and real sessions for any of the eight subjective symptoms surveyed, which included throbbing, itching, warmth, fatigue, headache, dizziness, nausea, and palpitation. The non-EHS group also showed no significant differences in any of the four stages between the two sessions for any of the eight subjective symptoms surveyed except warmth in stage II ($P = 0.046$). The scores of warmth at stage I and II for the sham session in the non-EHS group were 1.06 and 1.25, respectively, while those for the real session were 1.00 and 1.00, respectively. This significant difference clearly did not result from exposure because there was an increase in the mean score of the sham exposure with no change in that of the real exposure.

Percentage of Belief of Being Exposed

Table 1 shows the percentages of subjects who believed they were being exposed during pre-exposure, exposure (real or sham), and post-exposure in the EHS and non-EHS groups. In order to compare the percentages of belief of being exposed during the exposure, we applied the Wilcoxon signed-rank test and found no significant difference between real and sham exposures in the EHS ($P = 0.637$) and non-EHS groups ($P = 0.317$). To test whether there were any delayed effects of real exposure on post-exposure, we applied the same test and found no significant difference in the percentages of those who believed they were being exposed following real and sham exposures in the EHS ($P = 0.782$) and non-EHS groups ($P = 0.655$). Testing whether the subjects were in the same condition before the real and sham exposures, we found that there was no significant difference during pre-exposure between the real and sham exposures in the EHS ($P = 0.414$) and non-EHS groups ($P = 0.157$). To test whether the subjects were in the same condition throughout all the sham exposure sessions, we applied the Kruskal–Wallis test and found no difference in the percentages of those who believed they were being exposed among pre-exposure, sham exposure and post-exposure in the EHS ($P = 0.757$) and non-EHS ($P = 0.694$) groups.

Figure 5A,B shows the percentages of subjects who believed they were being exposed according to the inquiry numbers of the EHS and non-EHS groups in the sham and real exposure sessions, respectively. Even though there were significant differences between the EHS and non-EHS groups in inquiries Nos. 3 and 5 during the real exposure (Fig. 5B), there were also significant differences in inquiries Nos. 4 and 5 during the sham exposure (Fig. 5A). Therefore, it seems that the significant differences between the EHS and non-EHS groups in inquiries Nos. 3 and 5 during real exposure were not caused by the real exposure. The same reasoning applies to the significant differences in No. 7 during post-exposure in both sham and real exposures sessions. Even though the percentages of belief of being exposed in the EHS group are higher than those of the non-EHS group in all inquiry numbers during real exposure (Fig. 5B), higher percentages were also observed in pre-exposure, sham exposure and post-exposure for both sessions. Therefore, there was no evidence that the EHS group perceived the magnetic fields better than the non-EHS group. This statement probably results from the bias that EHS persons believe they can feel magnetic fields, as reported by Nam et al. [2009].

DISCUSSION

Neither the EHS nor the non-EHS group showed significant differences in heart or respiration rates between real and sham exposures or between the stages. In the case of LFP/HFP, however, there were significant differences between some stages during both real and sham sessions in the EHS group only. Hjortskov et al. [2004] reported that psychological stress could result in an increased LFP/HFP. Because EHS individuals have more anxiety than non-EHS ones, according to Mueller et al. [2002], EHS individuals may be under more stress in situations of possible exposure to environmental factors.

<table>
<thead>
<tr>
<th>Group</th>
<th>Session</th>
<th>Pre-exp (%)</th>
<th>$P$-value</th>
<th>Exp (%)</th>
<th>$P$-value</th>
<th>Post-exp (%)</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EHS ($n = 15$)</td>
<td>Real</td>
<td>33.3</td>
<td>0.414</td>
<td>52.0</td>
<td>0.637</td>
<td>60.0</td>
<td>0.782</td>
</tr>
<tr>
<td></td>
<td>Sham</td>
<td>46.7</td>
<td></td>
<td>54.7</td>
<td></td>
<td>57.8</td>
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</tr>
<tr>
<td>Non-EHS ($n = 16$)</td>
<td>Real</td>
<td>6.3</td>
<td>0.157</td>
<td>12.5</td>
<td>0.317</td>
<td>18.8</td>
<td>0.655</td>
</tr>
<tr>
<td></td>
<td>Sham</td>
<td>18.8</td>
<td></td>
<td>15.0</td>
<td></td>
<td>20.8</td>
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that they attribute their symptoms to. Lyskov et al. [2001] also indicated that EHS subjects had an imbalance of the autonomic nervous system regulation. Therefore, the significant increase in LFP/HFP with time in the sham session of the EHS group (Fig. 4B) could have resulted from factors other than field exposure such as psychological stress, anxiety, environmental factors, or an imbalance of the autonomic nervous system.

For symptoms attributed to magnetic field exposure, the non-EHS group showed significantly increased warmth only during non-exposure ($P = 0.046$) while the EHS group did not. This finding is not reasonable and may have resulted from factors other than exposure. Lonne-Rahm et al. [2000] and Oftedal et al. [2007] reported that symptoms might result from the nocebo effect.

There were no significant differences in the percentages of those who believed they were being exposed between the real and sham exposures in the EHS and non-EHS groups. Mueller et al. [2002] reported that EHS was not a prerequisite for the ability to consciously perceive 50 Hz EMFs at 100 V/m and 6 μT, which was lower than in the current study. A recent review by Röösli [2008], although not reporting on ELF EMFs, also concluded that the vast majority of individuals who claimed to be able to sense low-level RF-EMFs were not able to do so under double-blind conditions.

There were no significant differences in the percentages of those who believed they were being exposed between the post-real and post-sham exposures in the EHS and non-EHS groups. There were also no significant differences in the percentages of belief in the pre-exposure periods between the real and sham exposures in the EHS and non-EHS groups. There were no differences in the percentages of belief among the pre-exposure, sham exposure, and post-exposure periods in the EHS and non-EHS groups. Therefore, our experimental protocol seems...
minimally biased since we confirmed that there were no delayed effects, no differences in pre-exposure condition, and no differences in the percentage of those who believed they were being exposed among the pre-exposure, sham exposure, and post-exposure periods.

CONCLUSION

The majority of studies on EHS attributed to ELF fields have not provided any support for a casual relation between EMF exposure and symptoms or physiological reactions. However, only a few of these studies simultaneously investigated physiological parameters, subjective symptoms, and ELF EMF perception in both EHS and non-EHS groups with a minimally biased protocol. In conclusion, 60 Hz, 12.5 μT magnetic field exposure did not have any effects on heart rate, respiration rate, HRV, or subjective symptoms in either group. As for perception, there was also no evidence that the EHS group perceived the magnetic field better than the non-EHS group. Therefore, considering the physiological data analyzed, the subjective symptom results, and the percentages of those who believed they were being exposed, the origin of the subjective symptoms experienced by EHS individuals is not magnetic field exposure.

REFERENCES


