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Brief Communication

Novel Exposure Units for at-Home Personalized Testing of Electromagnetic Sensibility

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Previous experimental studies on electromagnetic hypersensitivity have been criticized regarding inflexibility of choice of exposure and of study locations. We developed and tested novel portable exposure units that can generate different output levels of various extremely low frequency magnetic fields (ELF-MF; 50 Hz field plus harmonics) and radiofrequency electromagnetic fields (RF-EMF). Testing was done with a group of healthy volunteers ($n = 25$ for 5 ELF-MF and $n = 25$ for 5 RF-EMF signals) to assess if units were indeed able to produce double-blind exposure conditions. Results substantiated that double-blind conditions were met; on average participants scored 50.6% of conditions correct on the ELF-MF, and 50.0% on the RF-EMF unit, which corresponds to guessing probability. No cues as to exposure conditions were reported. We aim to use these units in a future experiment with subjects who wish to test their personal hypothesis of being able to sense or experience when being exposed to EMF. The new units allow for a high degree of flexibility regarding choice of applied electromagnetic signal, output power level and location (at home or another environment of subjects' choosing). Bioelectromagnetics. 37:62–68, 2016. © 2015 Wiley Periodicals, Inc.

Key words: radiofrequency electromagnetic fields; electromagnetic sensibility; electromagnetic hypersensitivity

INTRODUCTION

Individuals who attribute their health complaints to electromagnetic fields (EMF) are often referred to as "electromagnetic hypersensitive" (EHS) [Baliatsas et al., 2012]. It has been suggested that EHS is possibly linked to self-reported ability to sense exposure to EMF, or "electromagnetic sensibility" [Leitgeb and Schröttner, 2003]. Electromagnetic sensibility may be reported by subjects as being able to sense fields or by experiencing (transient) discomfort or symptoms upon exposure. There is no scientific evidence corroborating electromagnetic sensibility exists. The majority of previous experimental studies did not show that some people were better than expected by chance to detect EMF exposure [Mueller et al., 2002; Röösli, 2008]. Several of these experiments included groups of EHS and non-EHS people [Röösli, 2008].

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Previous experimental studies on EHS have been criticized by affected people because study participants had to travel to the respective study location and exposure received during travel hampered them from being able to detect exposure. In addition, participants were tested in the unfamiliar environment of an anechoic chamber, and on predefined frequencies, signal types, or exposure levels they did not necessarily report sensing or having problems with [Schooneveld, 2013].

To overcome these limitations, we developed novel, portable exposure units able to generate a multitude of real-life EMF signal types: several extremely low frequency magnetic fields (ELF-MF) as well as radiofrequency electromagnetic fields (RF-EMF). Unit portability allows testing at a location chosen by participant. Here we report on our pre-test of both our exposure units with a group of healthy volunteers with the aim of assessing if double blind exposure conditions could indeed be realized in practice.

METHODS

Exposure Units

We developed portable exposure units designed in a flexible way to accommodate the possibility to personalize future testing procedures for participants, such as at requested frequencies, signal types, exposure levels, and duration of exposure conditions and breaks between conditions. Units are connected with a tablet that controls exposures. Settings include open, single blinded or double blinded exposure conditions, with computerized randomization schemes. Exposures of volunteers did not exceed reference field levels for the general public [ICNIRP, 1998; ICNIRP, 2010] at any time. All relevant system parameters were stored in encrypted log files, allowing full reproducibility of experiments.

ELF-MF Exposure Unit

The ELF-MF unit consists of one plastic box (15 × 40 × 115 cm, about 16 kg) with wheels to be able to move it to different places. It can generate five different types of exposure signals, one at a time. Selectable ELF-MF exposure signals were developed with input from a national EHS self-help group: a 50 Hz sinus signal and four more signals that have varying degrees of additional frequency components ("dirty electricity.") These signals correspond to fields as they can occur when in the vicinity of a power line, or close to a light emitting diode (LED) lamp, a vacuum cleaner or a ventilator. The power line signal is simulated with maximum accepted distortion for low to medium voltage power systems by the International Electrotechnical Commission [IEC, 1996], covering frequency components between 50 and 1250 Hz. Both LED lamp and vacuum cleaner signal include major frequency components of 100 and 1000–5000 Hz; the ventilator-type signal works with major frequencies of 300 and 6000 Hz (Supplementary Fig. 1).

In experimental set-up, the exposure unit is stood upright with help of a small rack (supplementary Fig. 3), and coils generating the ELF-MF field are then situated at a height of 95 cm above ground (coil center, with coil dimension of 33 × 39 cm). The exposure unit

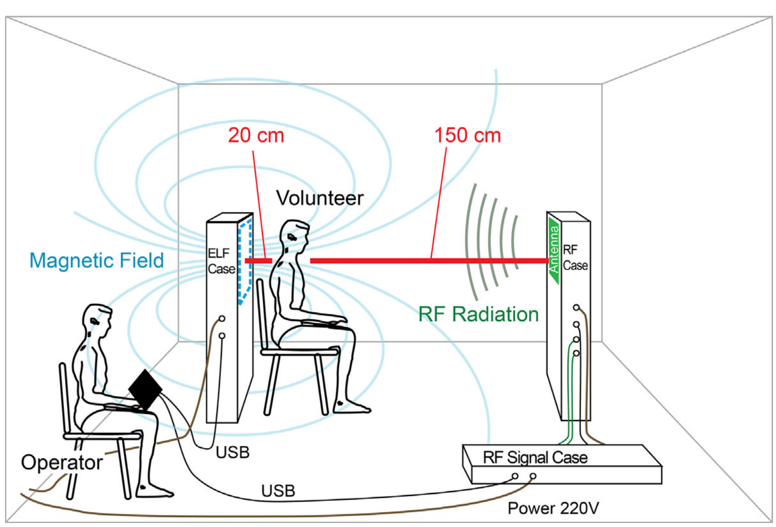

Fig. 1. Placement and configuration of ELF-MF and RF-EMF exposure unit.

is placed behind a sitting test person at a distance of 20 cm to the body (Fig. 1). A maximum exposure averaged across the upper body area at a level of up to 15 μT (rms) can be realized, with a maximum localized peak exposure of 60 μT at the volunteer's back and a minimum of 4.5 μT at the forehead (Supplementary Fig. 2). Lower exposures can be selected.

RF-EMF Exposure Unit

RF-EMF exposure unit consists of two boxes of same size and approximately same weight as ELF-MF unit. Boxes have to be connected to each other and to the tablet (Supplementary Fig. 3). It can generate one of the following signals, one at a time: Either mobile phone base station GSM or UMTS downlink signals (900, 1800 or 2100 MHz), cordless (DECT) phone or wireless internet connection (WiFi) signals (Supplementary Fig. 1). All types of RF-EMF have random voice/data information on signal modulation and thus represent those signals as they can be encountered under real-life conditions.

GSM signals are a mixture of four GSM and two enhanced data service for GSM evolution (EDGE) pulses and two empty slots, thus representing a pulsed signal. The UMTS signal represents a wideband code division multiple access (WCDMA) (data), 3.84 MCPS signal with 5 MHz bandwidth. The DECT signal mimics a base station connected to two handsets. This is again a strongly pulsed signal. Finally, WiFi signal represents a typical WiFi access point signal.

In RF-EMF exposure unit box, the broadband (800–960 and 1700–2500 MHz) dipole antenna with parasitic elements above a metal plate is positioned at a height of 100 cm above ground, and during an experiment, exposure unit is placed at a distance of 1.5 m from the test subject (Fig. 1). The 8 dBi directional antenna gain results in a maximum incident field exposure level of 6 V/m (rms) averaged over the upper body area of the test subject, which translates into a maximum localized peak exposure of 11.7 V/m around the knee of the volunteer, and a minimum of 1.6 V/m at the back (Supplementary Fig. 2). As with ELF-MF unit, lower output power levels can be applied.

Testing Procedure

We tested our exposure units with a group of healthy volunteers who were not selected based on any potential self-reported electromagnetic sensibility, although we inquired whether they had ever attributed health complaints to EMF exposure. We advertised on campus of Utrecht University (Utrecht, The Netherlands) and in an online database (www.proefbunny.nl). We included people between 18–65 years of age. Exclusion criteria were being deaf or blind, wearing hearing aids or having any obvious visual or hearing impairment. Per exposure unit, 25 volunteers were included. Volunteers received a small compensation for participation (10 Euro voucher). A subgroup of 15 people were willing to serve as volunteers for both ELF-MF and RF-EMF unit. The project was performed from January to April 2014 at Utrecht University in a designated well-lit, quiet office room on ground floor level. We first completed testing of ELF-MF unit followed by RF-EMF unit. Background exposure in the room was low, with <0.1 μT ELF-MF (Emdex Lite, [McDevitt et al., 2002]) and 0.2 V/m RF-EMF (ExpoM, [Roser et al., 2015]), based on a 1 min spot measurement at the place where volunteers were seated. During the experiment, volunteers sat on a wooden chair to ensure as little as possible interference with fields. Volunteers were asked to switch off any electronic devices they might have brought.

Per unit, every person was exposed to blocks of 10 times repeated sham or true exposure conditions per signal type and had to evaluate whether exposure was present or not. There were at least 3 sham and 3 exposure blocks within the 10 blocks of a given signal, but this was not communicated to participants. Within all exposure blocks, order and number of times true/sham conditions were applied in a computer-randomized order. ELF-MF unit was tested with five types of signals: 50 Hz sine signal, power line, LED lamp, vacuum cleaner and ventilator signal. RF-EMF unit was also tested with five types of signals: GSM900, GSM1800, UMTS, DECT and WiFi signal. This resulted in 50 true or sham exposure conditions per person for ELF-MF unit, and the same amount for RF-EMF unit. The five ELF and RF signal types were tested in the mentioned order, but we shifted the starting signal for each consecutive volunteer. The first volunteer was tested starting with the 50 Hz sine signal, followed by power line, LED, and other signals next; the second volunteer was first tested with power line signal, followed by LED signal and other signals, with 50 Hz sine signal coming last, and so on. The same procedure was applied to testing of RF-EMF unit.

Exposure duration was set to 30 s with 5 s break in between exposure conditions, resulting in total testing duration of about 35 min per volunteer per unit. Exposure strength was set to maximum of respective signal.

Participants were asked to record whether they thought exposure was present or not for each of the 50 conditions. We also inquired if volunteers had perceived any potential cues as to exposure conditions, such as click sounds, vibration or anything else they might have sensed. Our primary outcome was the overall proportion of correct answers across all signal types. We a priori calculated that if this overall percentage would exceed 54%, double-blinding was not given and exposure units would have to be adapted. Also, to assess if exposure conditions were truly double blind, in the sense that also the investigator controlling units during experiments should not be able to identify true from sham conditions, one of the authors also acted as a volunteer and evaluated all signals for both exposure units once.

The pre-test was approved by the medical ethical committee of the Utrecht Medical Centre, and we registered the trial prior to testing under www.trialregister.nl, number NTR4394.

Statistical Analysis

We calculated overall proportion of correct answers for ELF-MF and RF-EMF units separately. Since we tested 25 people per unit, we expected about one person per unit to achieve a higher percentage of correct answers than expected by chance (i.e., to have more than 32 out of 50 exposure conditions correct, corresponding to a P-value < 0.05).

We additionally estimated the proportion of correct answers per signal type, so over 10 applied exposure conditions per signal. We did this because we wanted to evaluate whether a particular signal was on average better detected by all volunteers, thus indicating a possible cue. Differences in the proportion of correct answers across signals was tested with a Kruskal–Wallis test. Because any potential click sounds or vibration or heat may be better perceived earlier or later during repeated testing, we also calculated the proportion of correct answers on a group level (across all volunteers), ordered by applied 50 exposure conditions, independent of applied signal type. Finally, we evaluated why participants reported they thought they sensed fields. Testing of group differences was done with Wilcoxon ranksum tests.

RESULTS

ELF-MF Unit

The 25 included volunteers were on average 28 years old with an age range of 19–50, 80% were women. Overall, volunteers correctly scored 50.6% (range 40–62%) of 50 ELF-MF exposure conditions, which corresponds to guessing probability. There was no evidence that some individuals were better than expected by chance to detect when exposure was present. Correct detection of power line signal over the whole group was 54%. The proportion of correct answers per signal type, calculated over 25 volunteers, is given in Figure 2A, differences across signal types were not statistically significant ($P = 0.4$). Evaluating the order in which exposures were applied did not provide evidence that maybe just the first few exposure conditions were detected better, or that detection improved over time. The proportion of correct answers over tested sequences did not indicate a trend over sequential exposure conditions (e.g., more correct answers in only the first few experiments, see also supplementary Fig. 4). Participants were somewhat more likely to think exposure was off (68% of conditions) than it really was (i.e., on average, exposure was absent in 50% of all conditions).

The majority of 25 participants (i.e., 21 people), described some kind of reaction to fields, although no informative cues with respect to conditions were reported. Those people reporting a reaction had about an equal percentage of correct answers compared with those who did not (51 vs. 48%, respectively). Most people reported some kind of tingling sensation (14 people, 56%) or very slight sensation of tension or pressure (8, 32%), and one person reported headache. Four people reported having perceived nothing at all, and several commented that some sensations likely were present because they concentrated hard on perceiving something. No click sounds or vibration or other cue was reported. Two of the 25 people reported ever having attributed health complaints to EMF exposure. The percentage of correct answers of those two people was somewhat higher compared to the rest of the group (57 vs. 50%), but not statistically significant ($P = 0.09$). We inquired about reactions after testing, so any reports cannot be related to specific signals.

RF-EMF Unit

Volunteers participating in testing of RF-EMF unit were on average 29 years old (range:19–58) and 68% were women. The overall percentage of correct answers for RF-EMF exposure conditions was 50% (range 40–66%). One person scored 66% correct on all signals. This means that overall, as expected, we observed one person who had more than 32 out of 50 exposure conditions correct.

The proportion of correct answers per signal type and per exposure condition is given in Figure 2B. Differences across signal types were not statistically significant ($P = 0.7$) and there was no obvious trend for better detection of signals or in earlier or later exposure conditions (Supplementary Fig. S4). Again,

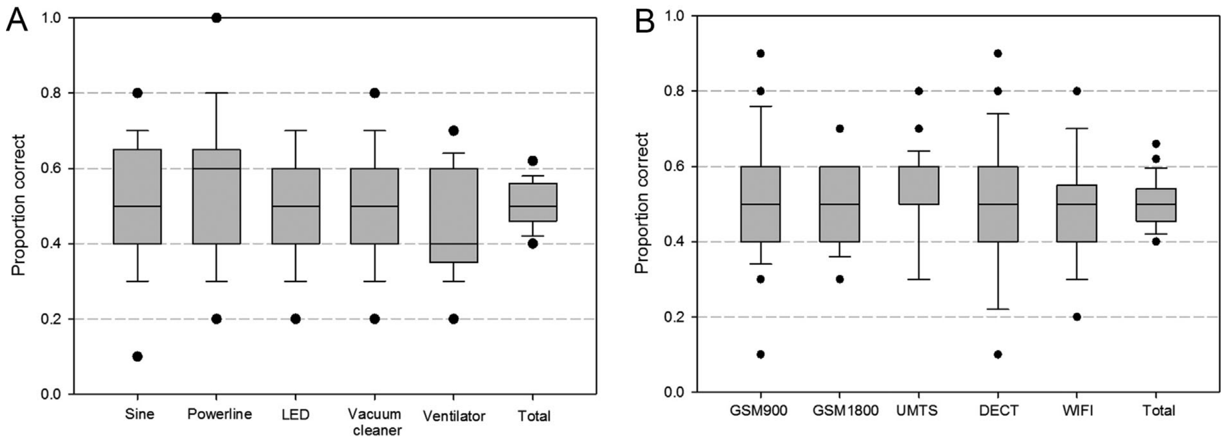

Fig. 2. Distribution of proportion correct answers per signal type. Box plots show distribution of correct answers of 25 healthy volunteers over 10 exposure conditions per signal and per exposure unit (= Total). Boxes display 25th to 75th percentile, middle lines the median, whiskers the 10th and 90th percentile and dots the minimum and maximum. **A**: ELF-MF unit; **B**: RF-EMF unit.

as with ELF-MF unit, participants thought it was more likely that exposure was absent (70% of conditions), while it was present on average in half of conditions. As with ELF-MF unit, no one reported cues (e.g., light, sounds), but many participants (19, 76%) reported some kind of reaction. These were again not predictive regarding presence or absence of exposure. People with a reaction had as many correct answers compared with those who did not (50% vs. 50%). Tingling was again the most frequent reported sensation (9, 36%). During RF-EMF testing, no volunteer reported attributed health complaints to EMF exposure.

Finally, automatically generated log files unblinded after finalizing the tests, confirmed correct working order of both exposure units for all applied exposure conditions. The study assistant was also not able to identify exposure and scored 52% correct answers on both units.

DISCUSSION

We developed novel, portable exposure units that can generate a multitude of ELF-MF as well as RF-EMF type of signals as they can be encountered under real-life conditions. We assessed if our exposure units were able to produce double-blind exposure conditions with a group of healthy volunteers. There was no evidence that units provided any cues (like click sounds) from which subjects could distinguish whether exposure was present or absent better than expected by chance. There was also no evidence that any specific signals were better detected than others, or that people performed worse or better over time. This applied to both ELF-MF and RF-EMF units.

Strength of our study is that we performed a relatively large number of exposure conditions that allowed us to test if people were able to perceive when exposure was present or not. Our test is in line with the literature that does not provide evidence that healthy people can perceive when being exposed to EMFs [Röösli et al., 2010]. However, most previous studies have evaluated electromagnetic sensibility on a group level and not an individual level. Earlier studies that have applied repeated testing of study participants have provided no evidence that individuals were able to perceive when being exposed to RF-EMF [Radon and Maschke, 1998; Kwon et al., 2008]. Of studies where volunteers were exposed repeatedly to an ELF-MF signal, one study reported a higher than expected number of participants (7 of 63, $P = 0.04$) who were better than chance to detect when exposure was present or absent [Mueller et al., 2002]. One recent publication on 29 EHS and 42 non-EHS people reported one individual who was near-perfect in detecting a 50 Hz sine field applied to the arm in repeated, randomized 20 times true or sham exposure conditions at a strength of about 500 μT, although this corresponded to a higher exposure level than what was applied in our study [Köteles et al., 2013]. It is reassuring for our planned experiment with people reporting electromagnetic sensibility that we did not observe people who were able to detect exposure because that means that double-blind exposure conditions can be achieved.

Another strength of our new exposure units is that they are able to generate different types of fields.

In particular, ELF-MF units can generate signal types that have additional frequency components added, also called "dirty electricity." To our knowledge, this has not been applied before, as the majority of studies so far have used primarily a sine 50 or 60 Hz field in provocation studies [Cook et al., 2002, 2006; Barth et al., 2010]. A few earlier studies also applied 10 or 20 Hz [Cook et al., 2002]. These sine fields are not necessarily those that EHS people report reacting to [De Vocht, 2010]. Our new exposure units now provide the opportunity to personalize applied exposures in future experiments and choose settings fitting the report of each participant wishing to be tested for electromagnetic sensibility.

Limitation of our testing room was that the exposure situation was not as standardized as if we had performed testing in a shielded laboratory room, where exposure levels can be fully controlled. However, we checked background exposure to both ELF-MF and RF-EMF fields, and in both cases exposure was at background levels as they usually encountered in residences [Schüz et al., 2000; Joseph et al., 2010]. The exposure that we added was manifold higher compared to what was in the testing room, which means that we do not expect that background exposure could have interfered with applied exposures.

In conclusion, our novel exposure units allow a flexible way of offering people the possibility to verify their hypothesis of reacting within short time periods to exposure to different types of EMF signals. In particular, signals that people report reacting to but that were never tested before can be applied.

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REFERENCES

Baliatsas C, Van Kamp I, Lebret E, Rubin GJ. 2012. Idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF): A systematic review of identifying criteria. BMC Public Health 12:1–23.

Barth A, Ponocny I, Ponocny-Seliger E, Vana N, Winker R. 2010. Effects of extremely low-frequency magnetic field exposure on cognitive functions: Results of a meta-analysis. Bioelectromagnetics 31:173–179.

Cook C, Thomas A, Prato F. 2002. Human electrophysiological and cognitive effects of exposure to ELF magnetic and ELF modulated RF and microwave fields: A review of recent studies. Bioelectromagnetics 23:144–157.

Cook C, Saucier D, Thomas A, Prato F. 2006. Exposure to ELF magnetic and ELF-modulated radiofrequency fields: The time course of physiological and cognitive effects observed in recent studies 2001–2005). Bioelectromagnetics 27:613–627.

De Vocht F. 2010. "Dirty electricity": What, where, and should we care. J Expo Sci Env Epid 20:399–405.

ICNIRP (International Commission on Non-Ionizing Radiation Protection). 2010. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 hz to 100 kHz). Health Phys 99:818–836.

ICNIRP (International Commission on Non-Ionizing Radiation Protection). 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 74:494–522.

IEC (International Electrotechnical Commission). 1996. Assessment of emission limits for distorting loads in MV and HV power systems. IEC Technical Report IEC 61000:3–6.

Joseph W, Frei P, Röösli M, Thuróczy G, Gajsek P, Trcek T, Bolte J, Vermeeren G, Mohler E, Juhasz P. 2010. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. Environ Res 110:658–663.

Köteles F, Szemerszky R, Gubanyi M, Kormendi J, Szekrenyesi C, Lloyd R, Molnar L, Drozdovszky O, Bardos G. 2013. Idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF) and electrosensibility (ES)-are they connected? Int J Hyg Environ Health 216:362–370.

Kwon MS, Koivisto M, Laine M, Hämäläinen H. 2008. Perception of the electromagnetic field emitted by a mobile phone. Bioelectromagnetics 29:154–159.

Leitgeb N, Schröttner J. 2003. Electrosensibility and electromagnetic hypersensitivity. Bioelectromagnetics 24:387–394.

McDevitt JJ, Breysse PN, Bowman JD, Sassone DM. 2002. Comparison of extremely low frequency (ELF) magnetic field personal exposure monitors. J Expo Anal Environ Epidemiol 12:1–8.

Mueller CH, Krueger H, Schierz C. 2002. Project NEMESIS: Perception of a 50 hz electric and magnetic field at low intensities (laboratory experiment). Bioelectromagnetics 23:26–36.

Radon K, Maschke C. 1998. Gibt es Elektrosensibilität im D-Netzbereich: Ein 3-AFC-Doppelblindversuch. Umweltmed Forsch Prax 3:125–129 (In German).

Röösli M. 2008. Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: A systematic review. Environ Res 107:277–287.

Röösli M, Frei P, Mohler E, Hug K. 2010. Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations. Bull World Health Organ 88:887–896F.

Roser K, Schoeni A, Bürgi A, Röösli M. 2015. Development of an RF-EMF exposure surrogate for epidemiologic research. Int J Environ Res Public Health 12:5634–5656.

Schooneveld H. 2013. Elektrostess Handboek—Leren omgaan met ziekmakende elektromagnetische velden. In: Schooneveld H, Wageningen Verweij, editors. pp 129–130 (In Dutch).

Schüz J, Grigat J, Störmer B, Rippin G, Brinkmann K, Michaelis J. 2000. Extremely low frequency magnetic fields in residences in Germany. Distribution of measurements, comparison of two methods for assessing exposure, and predictors for the occurrence of magnetic fields above background level. Radiat Environ Biophys 39:233–240.

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