Aggregated Data from Two Double-Blind Base Station Provocation Studies Comparing Individuals with Idiopathic Environmental Intolerance with Attribution to Electromagnetic Fields and Controls

Stacy Eltiti[12], Denise Wallace[1], Riccardo Russo[1], Elaine Fox[13]

[1]Department of Psychology and Centre for Brain Science, University of Essex, Wivenhoe Park, Essex, U.K.

[2]Now at Rosemead School of Psychology, Biola University, La Mirada, CA., U.S.A.

[3]Now at Department of Experimental Psychology, University of Oxford, Oxford, Oxfordshire, U.K.

Corresponding Address:

Stacy Eltiti, Rosemead School of Psychology, Biola University, 13800 Biola Ave, La Mirada, CA. 90639. Tel: 562-903-4738. Fax: 562-903-4864. E-mail: stacy.eltiti@biola.edu

Running title: Aggregated Data RF-EMF Exposure

Grant: The initial provocation studies were funded by the Mobile Telecommunications and Health Research Programme (MTHR) Grant Rum 20 and Grant Rum 26. The additional analyses using aggregated data reported here did not receive any additional funding.

Abstract

Data from two previous studies were aggregated to provide a statistically powerful test of whether exposure to electromagnetic fields produced by telecommunication base stations negatively affect levels of well-being in individuals who report idiopathic environmental illness with attribution to electromagnetic fields (IEI-EMF) and control participants. A total of 102 IEI-EMF and 237 controls participated in open provocation trials and 88 IEI-EMF and 231 controls went on to complete double-blind trials in which they were exposed to electromagnetic fields from a base station emitting either a Global System for Mobile Communication and Universal Mobile Telecommunications System or a Terrestrial Trunked Radio Telecommunications System signal. Both experiments included a comparison sham condition. Visual analog and symptom scales measured subjective well-being. Results showed that IEI-EMF participants reported lower levels of well-being during real compared to sham exposure during open provocation, but not during double-blind trials. Additionally, participants reported lower levels of well-being during high compared to low load trials and this did not interact with RF-EMF exposure. These findings are consistent with a growing body of literature indicating that there is no causal relationship between short-term exposure to electromagnetic fields and subjective well-being in members of the public whether or not they report perceived sensitivity to electromagnetic fields.

Keywords: radio frequency electromagnetic fields, human health, mobile communications, electromagnetic hypersensitivity

INTRODUCTION

Idiopathic environmental illness with attribution to electromagnetic fields (IEI-EMF) [Hillert et al., 2006] is a condition in which individuals have a strongly held belief that the variety of symptoms (e.g., skin problems, cognitive difficulties, sleep disturbances, etc.) they experience are caused by exposure to radio frequency electromagnetic fields (RF-EMFs) from various devices (e.g., computers, mobile phones, base stations, Wi-Fi, etc.). However, comprehensive reviews of the literature consistently report that the scientific evidence does not support a causal relationship between exposure to RF-EMFs and the experience of symptoms in IEI-EMF or control individuals [Rubin et al., 2005, 2010; Kwon and Hämäläinen, 2010; Röösli et al., 2010]. This conclusion has not, however, gained much traction with either the media or the general public and scientific investigators have also been slow to accept the null hypothesis in this controversial field of research. It has been speculated, for instance, that null results may be due to the use of heterogeneous samples of IEI-EMF individuals who report sensitivity to a variety of devices [Hillert et al., 2008]. The assumption is that positive results would be obtained if the sample only contained individuals who specifically attributed their symptoms to a specific device (e.g., mobile phones) and that same device is used in the provocation study (e.g., mobile phone). However, those few studies using homogenous samples (mainly IEI-EMF individuals who report sensitivity only to mobile phones) have also found no connection between exposure to RF-EMFs and subjective well-being [Wilén et al., 2006; Oftedal et al., 2007; Furubayashi et al., 2009; Nam et al., 2009; Kim et al., 2012].

Despite the absence of scientific evidence for a relationship between exposure to RF-EMFs and subjective well-being, it is possible that low statistical power is an important factor that needs to be taken into account. Most studies, for instance, have had small sample sizes.

This problem was highlighted by a recent report from the Advisory Group on Non-ionizing Radiation (AGNIR) that stated, “The controlled conditions and use of blinding in these studies makes this a robust body of work, although the small samples sizes in some of the studies means that rare effects of RF field exposure may have been missed. This is particularly true for studies that have assessed people who report sensitivity to electromagnetic fields, where recruitment of participants is understandably difficult” [2012].

Despite the best efforts of researchers around the world, IEI-EMF individuals are understandably reluctant to undergo testing and often anticipate very negative experiences if they do agree to take part in scientific studies to assess the impact of RF-EMFs on health. As an aside, our experience with testing well over 100 IEI-EMF individuals is that most are pleasantly surprised and do not generally have strong negative experiences when they take part in this type of study. Nevertheless, it is very difficult to recruit IEI-EMF individuals and this has resulted in very small sample sizes in most studies. To illustrate, an examination of sample sizes obtained in recent provocation studies (shown in Table 1) reveals that the sample size varied greatly among the studies with the majority (N = 11, 57.9%) containing sample sizes of 20 or less with a median of 18 for studies utilizing mobile phones and considerably higher for base station studies (Median = 34.5). Critically, studies that included a priori power analyses suggested that the sample size for IEI-EMF participants needs to be at least 60 in order to detect a moderate within-subjects effect (d ~.50) with a power of .80 or greater [Rubin et al., 2006; Eltiti et al., 2007a; Wallace et al., 2010; Nieto-Hernandez et al., 2011]. Only two published studies [Rubin et al., 2006; Nieto-Hernandez et al., 2011] have been able to achieve the required IEI-EMF sample size. Besides sample size, repeatedly testing the same individuals is another way to increase power. For example, the study by Oftedal et al. [2007] was able to achieve a power of .96 by repeatedly testing a small group of IEI-EMF individuals.

Larger sample size is one way in which we can increase the power of the statistical analyses to detect even a small effect of RF-EMF exposure on well-being. Another method is to increase the magnitude of the effect of RF-EMFs on subjective well-being. According to the "last drop" hypothesis it is only under stressful conditions that RF-EMF exposure affects well-being [Lyskov et al., 2001, 2006]. Consequently, a high stress task is expected to exaggerate any symptoms participants experience that are due to RF-EMF exposure thereby making it easier to detect its effect and increasing the power of the experiment. The previous two studies did manipulate stress by having a low load condition (participants watched a nature video) and a high load condition (participants engaged in tasks that were cognitively taxing).

Comment [S1]: I've moved this paragraph. It used to appear below, but I'm think it would fit in better here. What

In order to overcome the problem of inadequate sample size, the present study examined aggregated data from two previous studies conducted by our research group [Eltiti et al., 2007a; Wallace et al., 2010]. Furthermore, it sought to directly test the last drop hypothesis by comparing participants' well-being during low and high load conditions. Not only was there a high degree of similarity in how the two experiments were conducted (same research group, laboratory, measures of well-being, etc.), there was also a high degree of similarity in the characteristics of the RF-EMF fields used (e.g., telecommunication base station signals, same RF-EMF generating equipment, same power flux density, etc.). Likewise, the high load tasks used in the respective studies are considered to involve the same cognitive process that is, working memory. In fact, a component of the operation span task involves mental arithmetic. Given this high degree of similarity along with the fact that IEI-EMF participants often report the same if not similar symptoms from exposure to various RF-EMF sources, it was deemed feasible to combine the data in order to provide a more definitive examination of the effect of RF-EMF produced by telecommunication base stations on levels of well-being in IEI-EMF individuals.

In the present study, the data from both open provocation and double-blind trials from our two previous studies [Eltiti et al., 2007a; Wallace et al., 2010] were aggregated and analysed, following that our power calculations for both parametric and non-parametric tests indicated a high degree of sensitivity to detect an effect. It was predicted that during the open provocation tests, IEI-EMF participants would report lower levels of subjective well-being during a real exposure compared to sham; with no difference occurring for control participants. If there is a relationship between exposure to RF-EMFs and symptoms in IEI-EMF individuals that had not been previously detected due to a lack of power then, under double-blind conditions IEI-EMF individuals should report lower levels of subjective well-being during real compared to sham exposure. The last drop hypothesis predicts that the magnitude of this effect would be larger during the high load compared to the low load condition or might only occur under high load conditions. If there is no causal link between exposure to RF-EMFs and subjective well-being in IEI-EMF or control individuals then no difference should be found between real and sham exposure even under conditions of high load. Our sample size allows us to adequately test the null hypothesis.

METHODS

Participants

A total of 56 IEI-EMF and 120 control participants, from what will henceforth be referred to as Experiment 1 [Eltiti et al., 2007a], and 51 IEI-EMF and 132 controls participants, from what will henceforth be called Experiment 2 [Wallace et al., 2010], completed the open provocation portion of each study. From those, 44 IEI-EMF and 114 control participants from Experiment 1 and 48 IEI-EMF and 132 control participants from Experiment 2 went on to complete the double-blind portion of each study. Of those, 20 participants (5 IEI-EMF and 15 controls) from the open provocation and 19 participants (4 IEI-EMF and 15 controls) from the double-blind portion took part in both studies; therefore, only their data from Experiment 1 was included in the analyses leaving a total sample size of 102 IEI-EMF and 237 control participants for the open provocation trials and 88 IEI-EMF and 231 control participants for the double-blind trials. See the data analysis section below for detailed power analysis.

All participants were prescreened using the electromagnetic hypersensitivity questionnaire [Eltiti et al., 2007b]. Those that reported experiencing symptoms when exposed to RF-EMFs, in particular mobile phones and/or base stations, were included in the IEI-EMF group; whereas, control participants reported experiencing no symptoms connected to RF-EMF exposure. Among the IEI-EMF participants, 85.2% reported being sensitive to more than one RF-EMF device with 29.5% reporting sensitivity to mobile phones, 13.6% reporting sensitivity to telecommunication base stations, 47.7% sensitivity to both mobile phones and base stations, and 9.1% other RF-EMF devices. Inclusion and exclusion criteria for both studies was identical and a complete description of criteria can be found in Eltiti et al. [2007a] and Wallace et al. [2010]. All participants received a small payment and a contribution towards travel expenses. For both experiments, testing and data collection were conducted at the Electromagnetics and Health Laboratory located at the University of Essex (Colchester, UK). Ethical approval for Experiment 1 was obtained from the University of Essex ethics committee. Ethical approval for Experiment 2 was obtained from the University of Essex Ethics Committee, National Research Ethics Service, and East of England Ambulance Service Internal Ethics Group. Additional ethical approved had been obtained for Experiment 2 to recruit emergency workers for that study.

Biographical Information. The majority of IEI-EMF participants were female, white British, married, and did not have a chronic illness. For complete demographic information for both IEI-EMF and control participants and *P*-values for comparison tests see Table 2. Similarly, the majority of control participants were white British, married, and did not have a chronic illness; however, there were more male than female control participants. Chi-square analysis showed that there was no significant difference between IEI-EMF and control participants in terms of sex, ethnicity, or chronic illness. However, there was a significant difference between the groups in terms of marital status. Participants in the IEI-EMF group had a higher frequency of cohabiting and separated compared to participants in the control group. Although the average age of participants in the control group was older than the IEI-EMF group, independent samples Student's t-tests revealed that there was no significant difference between the groups in terms of age.

Design

Both experiments involved one open provocation session followed by double-blind sessions. Each session was held at least one week apart at approximately the same time of day (± 3 h). The exposures used in Experiment 1 were: Global System for Mobile Communication (GSM), Universal Mobile Telecommunications System (UMTS), and sham; while Experiment 2 used Terrestrial Trunked Radio Telecommunications System (TETRA) and sham. The data from the GSM and UMTS conditions in Experiment 1 were aggregated with the TETRA data from Experiment 2 to create the real exposure condition for the present analysis.

Exposure. For both the open provocation and double-blind trials, a larger percentage of participants (59.6% and 58.6%, respectively) received a real exposure condition prior to sham. Experiment 1 contained one sham and two separate exposure conditions (GSM and UMTS) resulting in more participants receiving a real exposure prior to sham. Chi-square analysis revealed that there was a significant difference for both the open provocation, χ^2 (1) = 12.46, $P <$ 0.001, and double-blind trials, χ^2 (1) = 9.48, $P = 0.002$. However, this pattern was not significantly different between IEI-EMF and control participants for either the open provocation, χ^2 (1) = 0.003, $P = 0.957$, or double-blind trials, χ^2 (1) = 0.38, $P = 0.539$. Thus, a greater number of both IEI-EMF and control participants received a real exposure as their first exposure.

Exposure System

For both experiments, the distance between the participant and base station antenna was 5 m in Experiment 1 and 4.95 m in Experiment 2. The laboratory was shielded for each study using the appropriate depth absorber to yield a shielding effectiveness greater than 60 dB at the tested frequency ranges for Experiment 1 and between 50 to 60 dB for 420 MHz for Experiment 2. In both studies, shielding effectiveness was independently tested by the National Physical Laboratory (Teddington, Middlesex, UK). The frequency bands corresponding to the different exposure conditions were as follows: 420 MHz for TETRA, 900 and 1,800 MHz for GSM, and 2020 MHz for UMTS. For all exposure conditions, the power flux density was 10 mW/m^2 over the area where the participant was seated. During the sham condition no signal was transmitted; therefore, the power was nil. The exposure system was regularly calibrated and found not to exceed ±3 dB of tolerance in Experiment 1 and ±1 dB of tolerance in Experiment 2. Detailed descriptions of the exposure system and laboratory can be found in Eltiti et al. [2007a] and Wallace et al. [2010].

Material and Procedures

Both Experiment 1 and Experiment 2 included open provocation and double-blind sessions. During the open provocation session, participants were told when the base station was on and off and in Experiment 1, if it was on, whether it was a GSM or a UMTS signal. Each exposure condition (sham, TETRA, GSM, and UMTS) lasted for 15 min during which participants watched a nature video and were prompted every 5 min to complete visual analog scales (VAS). A symptom scale was completed at the end of each exposure condition, following the final VAS. The majority of participants completed the VAS within the 30 s instruction prompt. Most participants completed their symptom scales in approximately 1 min, but were given longer if needed. The VAS and symptom scales were used to measure subjective well-being. The VAS measured: anxiety, tension, arousal, relaxation, discomfort, and fatigue. For each VAS participants placed an X on a 10 cm line, anchored on one end with “not at all” and the other “extremely,” to indicate how they felt at that moment. Symptoms taken from the electromagnetic hypersensitivity questionnaire [Eltiti et al., 2007b] were used to create the symptom scales. There were 57 symptoms and participants reported the degree to which they currently experienced each symptom using a 5-point Likert scale ranging from “not at all” to “a great deal.” Order of exposure (Experiment 1: sham, GSM, UMTS; Experiment 2: sham, TETRA) was counterbalanced across participants.

The double-blind provocation sessions for both experiments consisted of a 50 min exposure duration in which participants engaged in a 20 min low load task (watched a nature video), a 20 min high load task (mental arithmetic in Experiment 1 and operation span task in Experiment 2), two short cognitive tasks that measured attention and memory, and judged whether they believed the base station was “on” or “off.” During the low and high load tasks, participants were prompted every 5 min to complete VAS. Following each task and at the end of the session, participants were asked to record any symptoms using the symptom scales. The majority of participants completed the VAS within a few seconds and the symptoms scales within a minute. Order of exposure, load, and cognitive tasks were counterbalanced across participants. For a detailed description of the procedures involved in each experiment see Eltiti et al. [2007a] and Wallace et al. [2010].

Data Analysis

An average score for each VAS was calculated for the open provocation trials; however, for the double-blind trials an average score was calculate separately for the low and high load conditions. In order to create a single real exposure condition for Experiment 1 the data from the GSM and UMTS conditions were averaged. The VAS were positively skewed and thus a square root transformation was used to normalize the data; for the relaxation VAS the reflect and square root transformation was used as it was negatively skewed (high score indicated greater relaxation).

In Experiment 1, there were two real and one sham exposures; thus, there was an imbalance in the order of first exposure condition with the majority of participants receiving a real exposure first. In order to test for any higher order interactions with first exposure, preliminary 2 (group: IEI-EMF, control) x 2 (exposure: real, sham) x 2 (first exposure: real, sham) mixed factorial ANOVAs for the open provocation and 2 (exposure: real, sham) x 2 (group: IEI-EMF, control) x 2 (load: low, high) x 2 (first exposure: real, sham) mixed factorial ANOVAs for the double-blind trials for each VAS were conducted.

For the open provocation trials, after applying the Bonferroni correction ($\alpha = 0.008$) there was only one significant exposure x group x first exposure interaction for the relaxation VAS, *F*

(1,334) = 8.44, *P* = 0.004, partial η^2 = 0.03. Simple main effects analysis revealed that IEI-EMF participants were significantly more relaxed during the sham compared to real exposure irrespective of whether the first exposure was real, *F* (1,334) = 11.08, *P* = 0.001, partial η^2 = 0.03, or sham, *F* (1,334) = 41.14, *P* < 0.001, partial η^2 = 0.12. However, control participants only showed trend towards being more relaxed during sham compare to real exposure if their first exposure was real, *F* (1,334) = 3.71, *P* = 0.055, with no difference for controls whose first exposure was sham, *F* (1,334) = 0.64, *P* = 0.425.

For the double-blind trials, neither the exposure x group x first exposure, *F*'s < 2.55, *P*'s > 0.111, nor the exposure x group x load x first exposure, F's <4.61, *P*'s > 0.032, interactions were significant after applying the Bonferroni correction (α = 0.008). Thus, the data for both the open provocation and double-blind trials were reanalysed and are presented without first exposure. Furthermore, simple main effects analyses were conducted for both IEI-EMF and control participants to directly test the hypothesis that just IEI-EMF participants would report poorer levels of well-being during real compared to sham exposure.

Two scores were calculated based on responses to the symptoms scales: the total number of different symptoms a participant reported and a total symptom score (combined score for the eight subscales of the EHS questionnaire) indicating severity of symptoms [Eltiti et al., 2007b]. Scores were calculated for exposure by group for the open provocation and exposure by group during the low load, high load, and end of session recordings for the double-blind trials. Initial examination of the data revealed, similar to our previous studies [Eltiti et al., 2007a; Wallace et al., 2010], that the data had a high degree of skewness and kurtosis (many control participants reported no symptoms) and did not lend itself to transformation, thus non-parametric analyses were conducted. Wilcoxon Matched Pairs Signed Ranks tests were used to examine within-group differences and Mann Whitney U tests were used to examine between-group differences. Given the large number of statistical tests conducted, a Bonferroni correction was applied to the alpha level to reduce the likelihood of Type I errors. See corresponding tables for corrected alpha values.

Power analysis was calculated using G*Power 3.1.7 [Faul et al., 2007]. For data analysed using factorial ANOVAs (N = 319), the power to detect a small within-subject main effect or within-between subjects interaction (f = 0.10) [Cohen, 1988] was 0.95 for α = 0.05 and 0.82 for α = 0.008. For a medium between-subjects main effect (f = 0.25), the power was 0.99 for both α = 0.05 and α = 0.008. Power analyses were also conducted for the non-parametric tests assuming a normal distribution. For IEI-EMF participants (n = 88), there was a power of 0.99 for α = 0.05, 0.98 for α = 0.013, 0.97 for α = 0.008, 0.96 for α = 0.006 to detect a medium (d = 0.5) within-subjects effect for data analysed using the Wilcoxon Matched Pairs Signed Ranks Tests two-tailed. For control participants (n = 231), power was greater than .99 for all alpha values to detect a medium (d = .05) within-subjects effect. For data analysed using Mann Whitney U two-tailed tests, there was a power of 0.98 for α = 0.05, 0.95 for α = 0.013, and 0.93 for α = 0.008 to detect a medium (d = 0.5) between-subjects effect. Note, power values for various alpha levels were obtained to determine the power of the statistical test after Bonferroni corrections were applied to control for experimentwise alpha error.

RESULTS

Visual Analog Scales

Open provocation. Separate 2 (group: IEI-EMF, control) x 2 (exposure: real, sham) mixed factorial ANOVA’s were conducted for each VAS to determine the effect of exposure and group on subjective well-being. Means and standard errors for each group by exposure condition and *P*-values for the main effects, interaction, and simple main effects are presented in Table 3. The effect of exposure was significant for all VAS, *F*'s (1,336) > 44.61, *P*'s < 0.001, partial η^2's > 0.10, except for fatigue *F* (1,335) = 1.31, *P* = 0.254. Overall, participants reported higher levels of anxiety, tension, arousal, and discomfort, and lower levels of relaxation during real compared to sham exposure. The main effect for group was significant for all VAS, *F*'s (1,336) > 18.38, *P*'s < 0.001, partial η^2's > 0.05. IEI-EMF participants reported higher levels of anxiety, tension, arousal, discomfort, and fatigue and lower levels of relaxation compared to control participants.

With the exception of fatigue, *F*'s (1,335) = 0.11, *P*= 0.738, the interaction between exposure by group was significant, *F*'s (1,336) > 20.47, *P*'s < 0.001, partial η^2's > 0.05. The interactions were further analyzed using simple main effects comparing exposure for each group. This resulted in a significant effect of exposure for IEI-EMF participants, *F*'s (1,336) > 44.75, *P*'s < 0.001, partial η^2's > 0.11, who reported higher levels of anxiety, tension, arousal, and discomfort and lower levels of relaxation during the real compared to sham exposure. The effect of exposure for control participants was significant at $\alpha = 0.05$, but not at the corrected $\alpha = 0.008$ level, *F*'s (1,336) > 3.87, *P*'s $\leq$ 0.050, partial η^2's > 0.01. Exact *P*-values are displayed in Table 3.

Double-blind trials. Separate 2 (group: IEI-EMF, control) x 2 (exposure: real, sham) x 2 (load: low, high) mixed factorial ANOVAs were conducted for each VAS to determine the effect of exposure, load, and group on subjective well-being. Means and standard errors for each group by exposure by load condition and *P*-values for the main effects of exposure, load, and group can be found in Table 4. The results from the double-blind provocation trials showed a significant main effect for group for all VAS, *F*'s (1,317) > 12.57, *P*'s < 0.001, partial η^2's > 0.03. Overall, IEI-EMF participants reported higher levels of anxiety, tension, arousal, discomfort, and fatigue and lower levels of relaxation compared to control participants. There was also a significant main effect for load for all VAS, *F*'s (1,317)> 7.04, *P*'s ≤ 0.008, partial η^2's > 0.02, except for discomfort, *F* (1,317) = 1.02, *P* = 0.314. In general, participants reported higher levels of anxiety, tension, and arousal and lower levels of relaxation and fatigue during the high load compared to low load condition. The main effect for exposure was not significant for any of the VAS, *F's* (1,317) < 2.28, *P's* > 0.131. Thus, exposure did not have a significant effect on VAS.

Furthermore, none of the exposure x group, *F's* (1,317) < 2.55, *P's* >0.111; load x group, *F's* (1,317) < 0.18, *P's* > 0.676; exposure x load, *F's* (1,317) < 1.42, *P's* >0.234; or exposure x group x load, *F's* (1,317) < 3.57, *P's* >0.059, interactions reached significance at either the corrected 0.008 or uncorrected 0.05 alpha level. The only exception, was a significant load x group interaction for relaxation, *F* (1,317) = 15.87, *P* < 0.001, partial η^2 = 0.05. Simple main effects comparison revealed a significant effect of load for both IEI-EMF, *F* (1,317) = 83.96, *P* < 0.001, partial η^2 = 0.21, and control participants, *F* (1,317) = 503.08, *p* < 0.001, partial η^2 = 0.61. Both groups reported being more relaxed during the low compared to high load condition. The interaction seems to result from a larger mean difference in the control (-0.71) compared to IEI-EMF group (-0.47), with controls reporting significantly higher levels of relaxation during low load compared to IEI-EMF participants, *F*(1,317) = 27.88, *p* < 0.001, partial η^2 = 0.08. Simple main effects analyses comparing sham vs. real exposure for both IEI-EMF and control participants were not significant for any of the VAS at the corrected Bonferroni alpha level, *F*'s(1,317) < 4.93, *p*'s > 0.026. Exact *P*-values for these tests can be found in Table 4.

Symptom Scales

Open Provocation. There was a range of 0 to 45 for the total number of symptoms and 0 to 73 for total symptom score for the open provocation trials. Wilcoxon Sign Ranks tests were utilized to examine within-group differences in total symptom score and total number of symptoms between sham and real exposure conditions for the open provocation trials. The median, interquartile range, 25th, and 75th percentiles for the total symptom scores and total number of symptoms for IEI-EMF and control participants during real and sham exposure conditions and exact *P*-values are presented in Table 5. The results showed a significant effect of exposure for IEI-EMF participants who reported a greater severity of symptoms and total number of symptoms during the real compared to sham condition. However, there was no significant difference in either total symptom score or total number of symptoms between real and sham exposure for control participants. When the data for IEI-EMF and control participants were combined again there was a significant effect of exposure for both total symptom score and total number of symptoms.

Mann Whitney U tests were utilized to examine any between-group differences in either total symptom score or total number of symptoms during sham and real exposure conditions. There was a significant between-group difference for all conditions with IEI-EMF participants reporting both a greater severity of symptoms and more symptoms than controls during sham and real exposure conditions.

Double-blind trials. For the double-blind trials, total number of symptoms ranged from 0 to 43 and the total symptom scores ranged from 0 to 112. Analyses were conducted to examine the effect of exposure (real, sham) and load (low, high) on both the total symptom score and the total number of symptoms reported during the double-blind trials. The median, interquartile range, 25th, and 75th percentiles for the total symptom score and total number of symptoms by load by exposure for IEI-EMF and control participants and exact *P*-values can be found in Table 6. Wilcoxon Sign Ranks tests were utilized to examine within-group differences in total symptom score and total number of symptoms between sham and real exposure conditions. The results showed no significant difference between sham vs. real exposure during low load, high load, and end of session for either IEI-EMF or control participants or when IEI-EMF and control participants were combined. Thus, there appears to be no effect of exposure to RF-EMFs on either the total symptoms score or total number of symptoms experienced by participants.

In order to test for any between-group differences between IEI-EMF and control participants during the sham and real exposure during low load, high load, and end of the session, Mann Whitney U tests were performed. The results showed a significant difference in both total symptom score and total number of symptoms for all comparisons. Thus, IEI-EMF participants consistently reported a greater severity of symptoms and reported experiencing more symptoms than controls regardless of type of exposure and time of reporting.

To examine the effect of load on self-reported symptoms, Wilcoxon Sign Ranks tests were performed. The results showed that IEI-EMF participants reported significantly greater severity of symptoms and more symptoms during high compared to low load only during the sham exposure, but not during the real exposure condition. Control participants reported a greater severity of symptoms during high compared to low load during the real exposure condition; however, this difference was not significant once the Bonferroni correction was applied.

DISCUSSION

The purpose of this study was to test whether exposure to RF-EMFs produced by telecommunication base stations have a discernible effect on subjective well-being in those who report IEI-EMF and comparable control participants. By aggregating data across two independent studies we were able to form the largest sample size in studies of this kind to date. As expected, during open provocation trials, IEI-EMF participants consistently reported lower levels of subjective well-being during real compared to sham exposure as demonstrated in five out of the six VAS and both symptom severity and total number of symptoms reported. Control participants also reported lower levels of well-being during real compared to sham exposure; however, this difference was not significant after controlling for multiple tests. Additionally, IEI-EMF participants reported lower levels of well-being compared to control participants regardless of type of exposure.

The critical test was the double-blind conditions in which neither the participants nor researchers knew when participants received a real or sham exposure. During the double-blind trials, IEI-EMF participants once again reported lower levels of subjective well-being compared to control participants. However, the results showed no relationship between exposure to RF-EMFs and well-being as measured by VAS or symptom scales in either IEI-EMF or control participants, which is consistent with previous research [Zwamborn et al., 2003; Regel et al., 2006; Rubin et al., 2006; Wilén et al., 2006; Nam et al., 2009; Nieto-Hernandez et al., 2011]. Given the large sample size and statistical power of 0.82 to detect a small within-subjects effect and 0.99 to detect a medium between-subjects effect at $\alpha=0.008$ using ANOVA and 0.96 to detect a medium within-subjects effect ($\alpha = .006$) and 0.99 to detect a medium between-subjects effect ($\alpha = .008$) using non-parametric tests, we can be confident that the null results found in previous studies are accurate and are not Type II errors due to the studies being under-powered.

To increase confidence that these null results are valid, we also included a test of the last drop hypothesis; that the effect of RF-EMF on well-being would only be evident under high stress conditions [Lyskov et al., 2001, 2006]. The suggestion is that when an individual is in a high stress environment, he or she is physiologically more vulnerable to possible health effects from exposure to low-level RF-EMFs and therefore relationships between RF-EMF and health indicators will only be apparent under such conditions. Similar to the results of Lyskov et al. [2001), we too found no support for this hypothesis. Contrary to prediction, the results showed no reliable interaction between exposure by load or exposure by load by group; in fact both groups responded as expected under stressful conditions as the results in Tables 4 and 6 have shown. Therefore, stress, as a biological mechanism or catalyst, does not elicit or enhance an effect of RF-EMF exposure on subjective well-being in either IEI-EMF or control individuals.

The current study did contain a heterogeneous sample of IEI-EMF participants to achieve a larger sample size. Some would argue that a homogenous sample, just those who report sensitivity to base stations, might have yielded an effect of RF-EMF exposure on health. We cannot discount this possibility, although it does seem unlikely given the failure of studies that had utilized highly homogenous samples [Wilén et al., 2006; Oftedal et al., 2007; Furubayashi et al., 2009] to find any evidence of a relationship between specific type of RF-EMF exposure and health. Despite the use of a heterogeneous sample and lower level of RF-EMF exposure compared to mobile phones, IEI-EMF participants did report lower levels of well-being when exposed to RF-EMFs during the open provocation trials in which they knew when the base station was emitting a signal and when it was off. In our view, taking all the evidence into consideration, it seems unlikely that having a homogenous sample would have made a difference.

Given the high degree of similarity in two of our previous studies [Eltiti et al., 2007a; Wallace et al., 2010] we were able to combine the data to create the largest IEI-EMF sample to date and test with a high degree of statistical power (greater than 0.80 at α = 0.008 for small effect and greater than 0.95 at α = 0.006 for a medium effect) whether exposure to RF-EMFs from telecommunication base stations do indeed affect levels of subjective well-being. Our results showed no relationship between short-term exposure and subjective well-being in IEI-EMF or control individuals during double-blind conditions including those that contain a high level of stress. Several researchers have proposed that symptoms experienced by IEI-EMF individuals may result from a strongly held expectation of harm, known as the nocebo effect [Rubin et al., 2006, 2010; Oftedal et al. 2007; Röösli et al., 2010; Kwon, 2012], rather than actual exposure to RF-EMFs. This appears to be a viable explanation given that negative effects from RF-EMF exposure on subjective well-being in this study only occurred when IEI-EMF participants were aware that they were being exposed. This indicates that it is IEI-EMF individuals' belief that exposure to RF-EMFs will cause harm, rather than actual exposure itself, that results in the presence of symptoms in IEI-EMF individuals. Thus, we conclude with a recommendation that further research should focus on exploring the role of the nocebo effect in symptom expression among IEI-EMF individuals and the psychophysiological mechanisms that underlie the development of health-related symptoms. In terms of policy and prevention, well-established psychological interventions that focus on the formation of negative beliefs would appear to be the most likely to effectively reduce the incidence of IEI-EMF in society.

References

Advisory Group on Non-ionizing Radiation. 2012. Health effects from radiofrequency electromagnetic fields – RCE 20. Available from: http://www.hpa.org.uk/Publications/Radiation/DocumentsOfTheHPA/RCE20HealthEffectsfromRFElectromagneticFields/ [Accessed September 2013]

Augner C, Florian M, Pauser G, Oberfeld G, Hacker GW. 2009. GSM base stations: Short-term effects on well-being. Bioelectromagnetics 30:73-80.

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Sciences 2nd ed. Hillsdale, New Jersey: L Erlbaum Associates.

Eltiti S, Wallace D, Ridgewell A, Zougkou K, Russo R, Sepulveda F, Mirshekar-Syahkal D, Rasor P, Deeble R, Fox E. 2007a. Does short-term exposure to mobile phone base station signals increase symptoms in individuals who report sensitivity to electromagnetic fields? A double-blind randomised provocation study. Environ Health Perspect 115:1603-1608.

Eltiti S, Wallace D, Zougkou K, Russo R, Joseph S, Rasor P, Fox E. 2007b. Development and evaluation of the electromagnetic hypersensitivity questionnaire. Bioelectromagnetics 28:137-151.

Faul F, Erdfelder E, Lang A-G, Buchner A. 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39:175-191.

Furubayashi T, Ushiyama A, Terao Y, Mizuno Y, Shirasawa K, Pongpaibool P, Simba AY, Wake K, Nishikawa M, Miyawaki K, Yasuda A, Uchiyama M, Yamashita HK, Masuda H, Hirota S, Takahashi M, Okano T, Inomata-Terada S, Sokejima S, Maruyama E, Watanabe S, Taki M, Ohkubo C, Ugawa Y. 2009. Effects of short-term W-CDMA mobile phone base station exposure on women with or without mobile phone related symtoms. Bioelectromagnetics 30:100–113.

Hietanen M, Hämäläinen AM, Husman T. 2002. Hypersensitivity symptoms associated with exposure to cellular telephones: No causal link. Bioelectromagnetics 23:264–270.

Hillert L, Leitgeb N, Meara J. 2006. Working group report. In Hansson Mild K, Repacholi M, van Deventer E, Ravazzani P (eds): Electromagnetic Hypersensitivity. Proceedings: International Workshop on EMF Hypersensitivity. Prague: WHO, pp 15–26.

Hillert L, Åkerstedt T, Lowden A, Wiholm C, Kuster N, Ebert S, Boutry C, Moffat SD, Berg M, Arnetz BB. 2008. The effects of 884 MHz GSM wireless communication signals on headache and other symptoms: An experimental provocation study. Bioelectromagnetics 29:185–196.

Kim DW, Choi JL, Nam KC, Yang DI, Kwon MK. 2012. Origins of electromagnetic hypersensitivity to 60 Hz magnetic fields: A provocation study. Bioelectromagnetics 33:326-333.

Kwon MS, Hämäläinen H. 2010. Effects of mobile phone electromagnetic fields: Critical evaluation of behavioral and neurophysiological studies. Bioelectromagnetics 32:253–272.

Kwon MS, Choi JY, Kim SK, Yoo TK, Kim DW. 2012. Effects of radiation emitted by WCDMA mobile phones on electromagnetic hypersensitive subjects. Environ Health 11:69. DOI: 10.1186/1476-069x-11-69.

Lyskov E, Sandström M, Hansson Mild K. 2001. Provocation study of persons with perceived electrical hypersensitivity and controls using magnetic field exposure and recording of electrophysiological characteristics. Bioelectromagnetics 22:457-462.

Lyskov E, Hansson Mild K, Sandström M. 2006. Sensor reactivity and autonomous regulation in persons with perceived electrical hypersensitivity. In Hansson Mild K, Repacholi M, van Deventer E, Ravazzani P (eds): Electromagnetic Hypersensitivity. Proceedings: International Workshop on EMF Hypersensitivity. Prague: WHO, pp 87–92.

Nam KC, Lee JH, Noh HW, Cha EJ, Kim NH, Kim DW. 2009. Hypersensitivity to RF fields from CDMA cellular phones: A provocation study. Bioelectromagnetics 30:641–650.

Nieto-Hernandez R, Williams J, Cleare AJ, Landau S, Wessely S, Rubin GJ. 2011. Can exposure to a terrestrial trunked radio (TETRA)-like signal cause symptoms? A randomized double-blind provocation study. Occup Environ Med 68:339–344.

Oftedal G, Straume A, Johnsson A, Stovner LJ. 2007. Mobile phone headache: A double blind, sham-controlled provocation study. Cephalalgia 27:447–455.

Regel SJ, Negovetic S, Röösle M, Berdiñas V, Schuderer J, Huss A, Lott U, Kuster N, Achermann P. 2006. UMTS base station-like exposure, well being, and cognitive performance. Environ Health Perspect 114:1270-1275.

Röösli M, Frei P, Mohler E, Hug K. 2010. Systematic review of the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations. Bulletin of the World Health Organization 88:887-896F. DOI: 10.2471/BLT.09.071852. Available from: http://www.who.int/bulletin/volumes/88/12/09-071852/en/ [Accessed September 2013]

Rubin GJ, Das Munshi J, Wessely S. 2005. Electromagnetic hypersensitivity: A systematic review of provocation studies. Psychosom Med 67:224–232.

Rubin G, Hahn G, Everitt B, Cleare A, Wessely S. 2006. Are some people sensitive to mobile phone signals? Within participants double blind randomised provocation study. BMJ 332:886-891.

Rubin GJ, Nieto-Hernandez R, & Wessely S. 2010. Idiopathic environmental intolerance attributed to electromagnetic fields (formerly ‘electromagnetic hypersensitivity’): An updated systematic review of provocation studies. Bioelectromagnetics 31:1–11.

Wallace D, Eltiti S, Ridgewell A, Garner K, Russo R, Sepulveda F, Walker S, Quinlan T, Dudley S, Maung S, Deeble R, Fox E. 2010. Do TETRA (Airwave) base station signals have a short-term impact on health and well-being? A randomized double-blind provocation trial. Environ Health Perspect 118:735-741.

Wilén J, Johansson A, Kalezic N, Lyskov E, Sandström M. 2006. Psychophysiological tests and provocation of subjects with mobile phone related symptoms. Bioelectromagnetics 27:204–214.

Zwamborn APM, Vossen SHJA, van Leersum BJAM, Ouwens MA, Mäkel WN. 2003. Effects of global communication system radio-frequency fields on well being and cognitive functions of human subjects with and without subjective complaints. Available from: http://home.scarlet.be/milieugezondheid/dossiers/ gsm/TNO_rapport_Nederland_sept_2003.pdf [Accessed November 2003]