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Effects of personalised exposure on self-rated electromagnetic hypersensitivity and sensibility – A double-blind randomised controlled trial

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ABSTRACT

Background: Previous provocation experiments with persons reporting electromagnetic hypersensitivity (EHS) have been criticised because EHS persons were obliged to travel to study locations (seen as stressful), and that they were unable to select the type of signal they reported reacting to. In our study we used mobile exposure units that allow double-blind exposure conditions with personalised exposure settings (signal type, strength, duration) at home. Our aim was to evaluate whether subjects were able to identify exposure conditions, and to assess if providing feedback on personal test results altered the level of self-reported EHS.
Methods: We used double-blind randomised controlled exposure testing with questionnaires at baseline, immediately before and after testing, and at two and four months post testing. Participants were eligible if they reported sensing either radiofrequency or extremely low frequency fields within minutes of exposure. Participants were visited at home or another location where they felt comfortable to undergo testing. Before double-blind testing, we verified together with participants in an unblinded exposure session that the exposure settings were selected were ones that the participant responded to. Double-blind testing consisted of a series of 10 exposure and sham exposures in random sequence, feedback on test results was provided directly after testing.
Results: 42 persons participated, mean age was 55 years (range 29–78), 76% were women. During double-blind testing, no participant was able to correctly identify when they were being exposed better than chance. There were no statistically significant differences in the self-reported level of EHS at follow-up compared to baseline, but during follow-up participants reported reduced certainty in reacting within minutes to exposure and reported significantly fewer symptoms compared to baseline.
Conclusion: Our results suggest that a subgroup of persons exist who profit from participation in a personalised testing procedure.

1. Introduction

People who attribute their health problems to electromagnetic field (EMF) exposure are frequently referred to as 'electromagnetic hypersensitive' (EHS). There is no widely accepted consensus on what EHS is, how it can be assessed or how affected persons can be helped. In a survey of EHS individuals, Röösli et al. (2004) found that 56% claimed to develop symptoms within minutes of being exposed (Röösli et al., 2004). This suggests that at least for some EHS individuals, provocation experiments using short-duration exposures should be possible. The ability to sense exposure to EMF has been called 'electromagnetic sensibility', and it has been postulated that electromagnetic sensibility may be a prerequisite to becoming EHS (Leitgeb and Schröttner, 2003). Reviews on a range of provocation experiments with EHS individuals concluded that, in double-blind laboratory settings, there was no evidence for an improved ability to detect EMF in EHS, compared to

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non-EHS individuals (Röösli, 2008; Rubin et al., 2005; Rubin et al., 2010). It is unclear whether this result may prompt study participants to reconsider their electromagnetic hypersensitivity (Mueller et al., 2002; Nieto-Hernandez et al., 2008).

Previous studies were criticised by EHS self-help organisations in that many studies (with few exceptions (Leitgeb et al., 2008; Oftedal et al., 1995; Oftedal et al., 1999)) were performed in anechoic laboratories, obliging EHS persons to travel (Schooneveld, 2014). Travelling is associated with somewhat higher exposure levels compared to at home (Bolte and Eikelboom, 2012) and the reasoning was that travelling was stressful and therefore would hamper detection during the actual experiment. Another criticism concerned the choice of type of experimental signal: usually one exposure signal was chosen for the experimental set-ups (e.g. a 50-Hz sine signal (Mueller et al., 2002), or a UMTS signal (Regel et al., 2006)). Only occasionally (Leitgeb et al., 2008; Oftedal et al., 1995; Oftedal et al., 1999; Hillert et al., 2008; Oftedal et al., 2007) was a the type of signal selected that a person reported reacting to, or that reflected everyday exposures.

We have developed mobile exposure units that allow us to perform double-blind exposure tests with personalised exposure settings at home. This allows for personalised exposure, i.e. the use of the type of signal a person reports reacting to at a level and duration of their choice, and for immediate feedback on test results (Huss et al., 2016). In view of the study criticism, we offered persons the opportunity to verify their own hypothesis of being electromagnetic sensible or electromagnetic hypersensitive. Given previous study results, we hypothesised that people would be unable to identify when they were exposed, and we were interested to see if our procedure would stimulate reconsideration, i.e. if such a testing procedure would have an effect on their self-rated sensitivity and sensibility to EMF some months after testing.

2. Material & methods

2.1. Study design

To be able to assess the effect of double-blind testing on self-rated electromagnetic sensitivity and sensibility, we performed a randomised

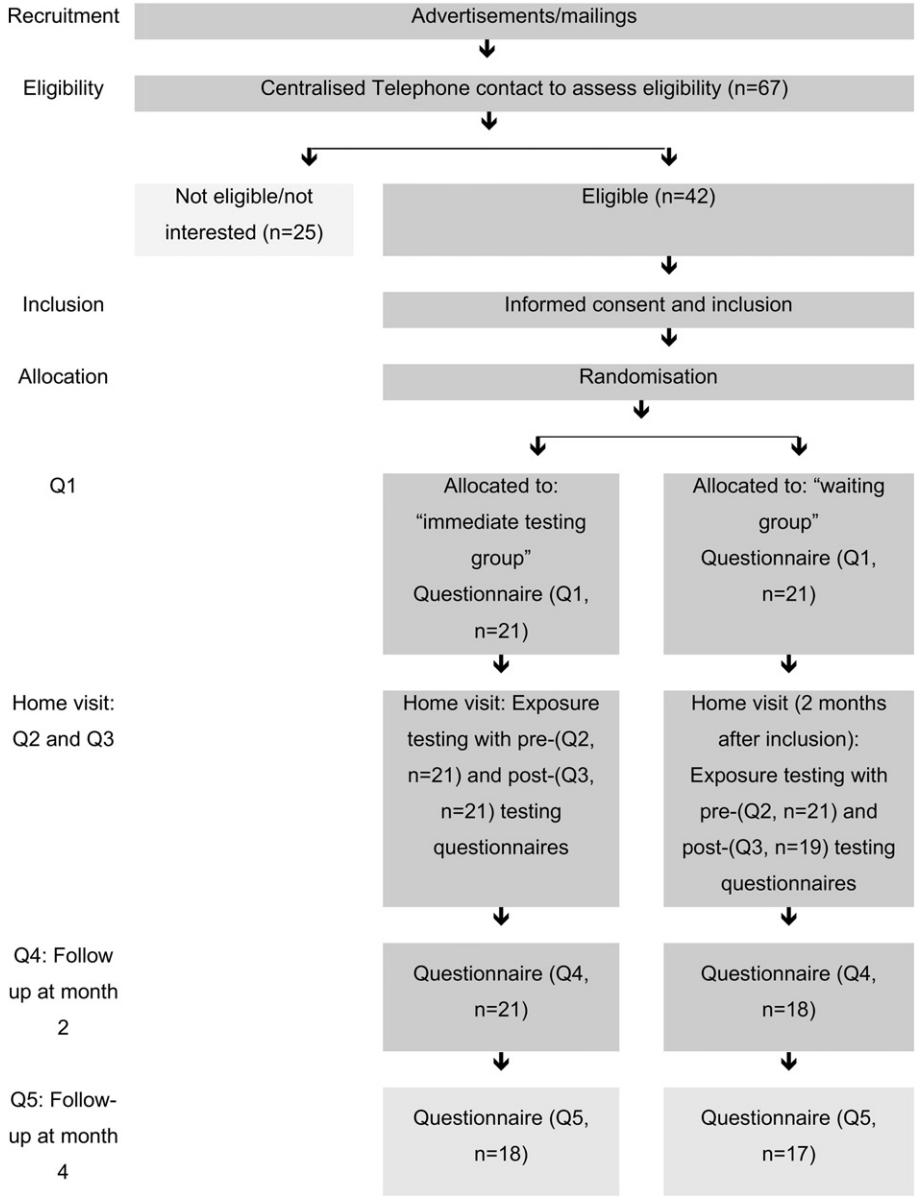

Fig. 1. Flow chart of study procedure. Trial flow chart. Q1 = baseline questionnaire, Q2 = pre-testing questionnaire, Q3 = post testing questionnaire, Q4 = questionnaire at 2 months follow-up, Q5 = questionnaire at 4 months follow-up.

controlled two-arm trial (see Fig. 1). We randomised participants to either immediate testing ("immediate testing group") with follow-up questionnaires at two and four months, or delayed testing ("waiting group") at two months with follow-up questionnaires at four and six months. The primary outcome was the self-reported electromagnetic sensitivity and sensibility two months after testing in the immediate testing group compared to the self-reported electromagnetic sensitivity and sensibility prior to testing in the waiting group, as measured on a 100 mm visual analogue scale (VAS). Time periods of two and four months post testing were selected to allow time for consideration of test results.

Randomisation into trial arms was based on computer-generated random numbers, printed on letters and sealed in opaque envelopes by an investigator without contact with study participants, using block-randomisation in blocks of six. The study was approved by the medical ethics committee of the University Medical Centre Utrecht (UMCU), the Netherlands, and registered prior to the study under NL45964.041.14 on https://www.toetsingonline.nl (Toetsingonline, 2016). All exposure values stayed well below international safety guideline limits, and we obtained an experimental license to use the specific carrier frequency by the Dutch authorities.

2.2. Participants

Adult participants (18 years or older) living in the Netherlands were included if they reported electromagnetic sensibility, i.e. the ability to sense one of the available experimental EMF signals within minutes of being exposed, or developing acute and transient health complaints that occurred and disappeared within about 15 min upon exposure of short duration. The following exclusion criteria applied: a) inability to complete the administered questionnaires or communicate with the study assistant, e.g. due to insufficient knowledge of the Dutch language or cognitive impairment; and b) self-reported time between start of exposure and sensing exposure or development of symptoms plus recovery time from symptoms exceeded 15 min. Study participants were recruited via a self-help EHS organization ("Stichting EHS"), municipal public health services ("GGD") and advertisements in local newspapers in Amsterdam and surrounding cities. We included participants between August 2014 and November 2015 into the study.

2.3. Study procedure

After inclusion, participants were randomised to immediate or delayed testing (Fig. 1), and were sent a baseline questionnaire (Q1). Participants were visited at home for the testing procedure and filled in a short questionnaire directly prior to testing (Q2). An unblinded exposure session was applied to determine the type of signal, signal strength and exposure duration that participants reported reacting to. This was followed by double-blind exposure or sham conditions in randomised sequence ("testing"). During testing, for each of the applied conditions and directly after each condition, participants specified on a form whether they thought exposure had been applied or not. Directly after testing, participants again filled in a short questionnaire (Q3) and then the test results were communicated to the participants, i.e. the percentage of correct on/off answers. Two and four months after participation, they were sent a follow-up questionnaire (Q4 and Q5, respectively).

2.4. Questionnaires

The baseline questionnaire (Q1) inquired about self-rated level of electromagnetic sensibility/sensitivity ("How sensitive are you to EMF in daily life?"); certainty regarding being electromagnetic sensible/sensitive ("How certain are you that you are sensible/sensitive to EMF in daily life?"); and certainty of reacting to EMF within minutes ("How certain are you that you react within minutes to specific EMF in daily life?"). These three core questions were repeated during the home visit also directly prior (Q2) and post testing (Q3, before receiving feedback on personal test results) and in the follow-up questionnaires (Q4 and Q5, see below). Answers to these three questions were provided on a 100 mm VAS scale, ranging from "not at all" to "very strongly"/"absolutely certain". Further items of the baseline questionnaire inquired about symptoms experienced during the previous four weeks, the burden each symptom had on the participants' life, and how certain the participants were that the symptom was linked to the exposure to EMF, see Table 1. We also asked for the motivation to participate in the study, at what age they had considered for the first time that they were sensitive to EMF ("chronicity"), and sociodemographic factors. Q3 additionally inquired about how participants had perceived the exposure.

In addition to the three core questions, follow-up questionnaires Q4 and Q5 again included questions on symptoms, burden of the symptoms and certainty about the link of the association of each symptom to EMF exposure.

2.5. Exposure units

Our exposure units have been previously described in detail (Huss et al., 2016). In brief, two mobile custom-made exposure units were developed for this project. Different types of non-ionising EMF can be generated: a) radiofrequency EMF ("RF-unit"): GSM 900 (925–960 MHz), GSM 1800 (1805–1880 MHz), cordless phone ("DECT phone", 1880–1900 MHz), UMTS (2110–2170 MHz), and WiFi (2400–2500 MHz); and b) extremely low-frequency magnetic fields ("ELF-unit"): a 50 Hz sine signal, or four different types of other signals with other frequency components added, also called "dirty electricity"; one at a time. The signals correspond to the most frequently occurring exposure sources of EMF in the general environment at home and at work, and includes mobile phone base stations, cordless landline phones, cordless internet connections (WiFi), power lines, but also magnetic fields as they can be generated from devices that are used with a power plug. Exposure levels can be set to a maximum of 6 V/m (average exposure levels at the upper body level) for radiofrequency EMF and up to 6.6 μT for the extremely-low frequency magnetic fields, depending on the chosen signal.

2.6. Experimental procedure during the home visit – open exposure

The experiment took place at the home of the participant or some other place where the person felt comfortable (implying that the participant did not, or at least not too strongly, feel exposed to electromagnetic fields at the respective location, this could for example be the house of family or friends). Places other than the own home were selected as test locations 3 out of 42 times.

We first applied an unblinded ("open") exposure session to confirm together with the participant that a signal had been selected at a field strength that the person reported to sense. We applied average exposure levels as they have been previously reported to occur in homes: about 0.2 V/m for radiofrequency fields (Bolte and Eikelboom, 2012), and 0.2 μT for extremely low frequency magnetic fields (Brix et al., 2001; Calvente et al., 2014). Higher or lower exposure level settings could be selected if a participant wished to increase or decrease the levels. We continued the experiment with the double-blind randomised experiment only if participants confirmed being able to sense the exposure. Identical settings as determined in the open session were subsequently applied during the actual experiment under double-blind conditions. The time settings for the duration of exposure conditions and breaks were also determined during the open session. Exposure conditions and breaks in between sessions were not allowed to exceed 15 min combined (i.e. a series of 10 conditions took a maximum of 150 min).

Table 1
Overview core and symptom questions asked per questionnaire wave.

	Baseline *Q1*	House visit (prior to testing) *Q2*	House visit (post testing) *Q3*	Follow up at month 2 *Q4*	Follow up at month 4 *Q5*
Self-rated level of electromagnetic sensibility/sensitivity	x	x	x	x	x
Certainty regarding being electromagnetic sensible/sensitive	x	x	x	x	x
Certainty of reacting to EMF within minutes	x	x		x	x
Number and type of symptoms	x			x	x
Burden of each symptom	x			x	x
Certainty that the symptom was linked to EMF exposure	x			x	x

2.7. Experimental procedure during the home visit – double-blind testing

The open exposure was followed by a series of randomised double-blind testing with exposure or sham conditions. These conditions were double-blind in that the order of the sham or exposure conditions was determined by a computer, and we had previously verified that neither healthy volunteers nor the study assistant perceived any cue (e.g. sounds) that gave away whether it was an exposure or a sham condition (Huss et al., 2016). Three to seven conditions were exposure conditions and participants were told that exposure would be applied at least once. This resulted in a total of 912 possible combinations, and achieving 8 out of 10 conditions correctly corresponded to a p-value of 0.055, for 9 and 10 correct conditions the p-values were 0.011 and 0.001, respectively.

The default amount of exposure/sham conditions was 20 to rule out chance findings, but for feasibility reasons (i.e., time spent testing for each participant), we stopped after 10 conditions to check if at least 8 out of 10 conditions had been identified correctly. If that was the case, we made a follow-up appointment to perform the remaining 10 tests as soon as possible. In this second home visit, the same procedure applied as for the first visit, except for the open exposure. If fewer than 8 out of 10 conditions were correct, participants were told their percentage of correctly identified conditions, and that they had not been able to identify when they were being exposed. We did not offer participants re-testing if they had fewer than 8 out of 10 conditions correct. This was done because although it is possible that people are unable to perceive the exposure they may by chance score correctly, but it is unlikely that people can truly perceive the exposure and yet by chance score incorrectly.

2.8. Outcomes

The three core questions on self-rated electromagnetic sensibility/sensitivity were defined a priori as our primary outcomes. We compared the ratings in the trial arms at two months after inclusion, which corresponded to ratings two months after testing in the immediate testing group, and to ratings immediately before testing in the waiting group. We additionally assessed: a) how many people were able to correctly assess whether exposure was on or off; b) the temporal change in the three core questions on self-rated electromagnetic sensibility/sensitivity at baseline, pre/post testing in the home visit, and the two and four months follow-up questionnaires after testing; and c) the change in the total number of symptoms and in the severity and attribution of symptoms to EMF at two and four months post testing versus baseline: For this severity-attribution-score we combined the perceived burden of a reported symptom with the self-reported strength of the attribution of that symptom with EMF exposure. Both perceived burden as well as the reported strength of an association were measured on a 41 mm VAS scale and subsequently weighted as a proportion of the VAS scale. For example, a reported headache with a perceived burden of 20 mm and an attribution strength of 10 mm on the VAS scale was counted as 1 (symptom) × (20/41) × (10/41). To derive the total severity-attribution score this calculation was summed for all reported symptoms for each questionnaire wave (i.e. for baseline Q1, and follow-up Q4 and Q5). This was done to take into account situations in which symptoms might persist, but their severity and/or attribution to EMF could have changed.

2.9. Statistical analysis

Differences between our two trial arms at two months after study inclusion were tested using chi-square tests for categorical values, and two sample t-tests for numerical values. Changes in the three core questions on electromagnetic sensibility/sensitivity pre/post testing at the home visit and at two and four months follow-up compared to baseline were analysed using multilevel mixed-effects linear regression with a random intercept per participant to account for repeated measurements; adjusted for age and sex. For one person with a repeated home visit we took the average of the ratings directly post-testing of the three core questions.

We tested for interaction of change of the three core questions across questionnaire waves with: (a) duration in years since they had first considered themselves to be sensitive to EMF ("chronicity", in tertiles); and (b) the motivation to participate in the study (comparing people reporting "I want to know whether I'm sensitive" to all others, assuming this group was most open to test results), in order to see whether these subgroups differed in longitudinal changes in reported sensibility/sensitivity. The same procedure was followed for the temporal change of reported number of symptoms and the severity-attribution score. We also adjusted the symptom models for season (winter vs. summer) when testing was performed, since symptom reporting may differ from summer to winter.

We additionally explored whether across the whole participant group correct scoring of the test conditions changed depending on the order of test conditions, i.e. if conditions were more likely to be more correctly assessed towards the first or last of the ten conditions. Data analysis was done using STATA, version 12, Stata Corp., Texas.

3. Results

67 persons initially contacted the study centre and 42 (61%) persons fulfilled the eligibility criteria and expressed interest in participation. Of the participants, 40 persons (95%) filled in at least one of the follow-up questionnaires, 39 persons filled in the follow-up questionnaire after two months and 35 persons the follow-up questionnaire after four months. Table 2 shows general characteristics of the study population. At baseline, the participants were on average 55 years (SD 12 years) with an age range of 29–78, and the majority were female (76%). More than half (62%) reported a high educational level and approximately one third (31%) were self-employed. Participants were on average 43 years (SD 14 years, age range 6–66) the first time they had considered they were sensitive to EMF, corresponding to 0.8 –<5 years in the "low chronicity" group, 5–12.2 in the "medium chronicity" group and >12.2–53 years in the "high chronicity" group. The median number of reported health complaints at baseline was four (interquartile range (IQR) 3–7). Total time duration of the home visit was approximately 2 h 45 min (interquartile range 2 h to 3 h 45 min).

Table 2
Characteristics of the study population.

		Total study group		Immediate testing group		Waiting group	
		N	%	N	%	N	%
Sex	Female	32	76	15	71	17	81
	Male	10	24	6	29	4	19
Age groups	≤35	2	5	2	10	0	0
	35–≤45	5	12	2	10	3	14
	45–≤55	14	33	8	38	6	29
	55–≤65	12	29	5	23	7	33
	>65	9	21	4	19	5	24
Education	Low	1	2	1	5	0	0
	Medium	15	36	8	38	7	33
	High	26	62	12	57	14	67
Work status	Self-employed	13	31	6	28	7	33
	Employed	9	21	5	24	4	19
	Retired	9	21	5	24	6	29
	Other[a]	11	26	5	24	4	19
Duration since having EMF problems[b]	0.8–<5 years	13	32	7	35	6	29
	5–12.2	15	36	9	45	6	29
	>12.2–53	13	32	4	20	9	42

[a] (e.g. homemaker, unemployed, disability pension).
[b] Cut-offs correspond to tertiles.

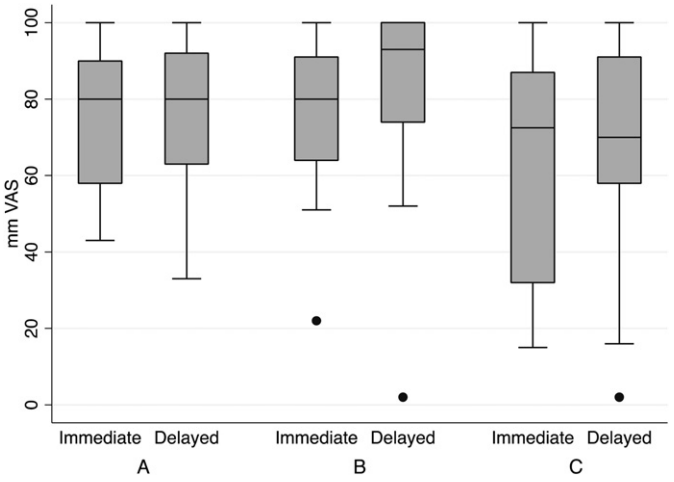

Fig. 2. Self-rated electromagnetic sensibility/sensitivity; comparing immediate testing group to waiting group. Self-rated electromagnetic sensibility/sensitivity reported two months after registration comparing participants in the immediate testing group (two months post testing, so including feedback on personal test results), and in the waiting group prior to testing. A: self-rated level of electromagnetic sensibility/sensitivity, B: certainty regarding being electromagnetic sensible/sensitive, C: certainty of reacting to EMF within minutes.

There were no statistically significant differences between the immediate testing group and waiting group regarding our three core questions on self-rated electromagnetic sensibility/sensitivity at baseline, age, sex, educational level, chronicity of sensibility/sensitivity to EMF and severity of health problems attributed to EMF (all $p > 0.05$). The majority (71%) reported that their main reason for participating was that they found it important that scientific research was being done on electromagnetic hypersensitivity and that they wanted to contribute to it; 14% wanted to confirm (for themselves) that they were sensitive to EMF; 17% wanted to show to others that they were sensitive to EMF, and 12% reported wanting to know if they were sensitive to EMF. Note that because participants gave multiple reasons, the numbers add up to >100%.

The majority of the participants (90%) wanted to be tested with radio frequency EMF (RF-EMF), in particular UMTS (41%), WiFi (38%), GSM900 or GSM1800 (14%) or a DECT (8%) signal. Tested field strengths for RF-EMF ranged between 0.2 and 6 V/m with a median of 0.44 and an interquartile range of 0.28 to 2.32 V/m. Four persons were tested with extremely low frequency fields, which included the signal of a power line (2×) and a light-emitting diode (LED) type of signal (2×), (Huss et al., 2016). Field strengths for ELF ranged between 0.15 and 6.6 μT, with two persons tested around the lower exposure level and two persons at the higher level.

Most of the participants (95%) reported immediately after the testing that they had perceived the EMF in some way, the majority mentioned some kind of tension or pressure (40%), a tingling sensation (28%), tightness in the chest or palpitations (21%), malaise (19%) or headache (16%). Two persons did not perceive EMF in the open exposure session and therefore did not continue with the double-blind exposure experiment. These persons did not fill in the questionnaire directly after the experiment (since not responding in the open session already implied the test result that they were not able to sense when being exposed under the experimental conditions), but did fill in the two and four months follow-up questionnaires.

3.1. Self-rated electromagnetic sensitivity and sensibility, comparing immediate testing to waiting.

Half of the study population ($n = 21$) were randomly assigned to the immediate testing trial group. Fig. 2 shows distributions of the three core questions on self-rated electromagnetic sensibility/sensitivity for people in the immediate testing arm (assessed at two months post testing, Q4) and the waiting group (assessed at two months after inclusion directly prior to testing, Q2). Differences in the immediate testing group were not statistically different from the waiting group (all $p > 0.4$).

3.2. Correct identification when exposure was present or absent

Overall, participants correctly scored 48% (range 20–80%) of the exposure conditions as being on or off, which corresponds to guessing probability. Participants who tested ELF-MF correctly scored on average 50% (range 20–70%) and those who tested RF-EMF correctly scored on average 48% (range 30–80%).

There were two persons who correctly scored 8 out of 10 in the first home visit. In the second home visit, however, one of these persons correctly scored 6 out of 10 correctly (overall 70% correct answers, indicating no ability to correctly identify when being exposed, p-value = 0.12). The second person did not want to be re-tested; the overall 8 out of 10 correct conditions thus corresponded to a p-value of 0.055.

3.3. Three core questions on self-rated electromagnetic sensibility/sensitivity and change in symptoms post vs. prior to testing

Across the whole study group (i.e. disregarding randomisation), there was very little temporal change in the level of self-rated electromagnetic sensibility/sensitivity over the duration of the project. On average people decreased their ratings by 2–3 mm on a 10 cm VAS, which was not statistically significant (Fig. 3). Participants were somewhat less certain (about −6 mm) about their own electromagnetic sensibility/sensitivity directly post testing compared to at baseline, but this effect was no longer present at two and four months after testing. The self-rated certainty of reacting within minutes to EMF exposure decreased (about −12 mm) over the duration of the project, and this effect was statistically significant ($p = 0.05$). The intraclass correlation coefficients (the proportion of variance in the outcome explained by the within-subject variation) were 0.72, 0.75 and 0.59 for these three core electromagnetic sensibility/sensitivity variables, respectively. This indicates that the certainty of responding within minutes to EMF varied more within a person, compared to the other two core measures.

At baseline, participants reported on average 4.7 symptoms they had experienced the previous month. In follow-up questionnaires at two and four months, participants reported fewer symptoms, namely on

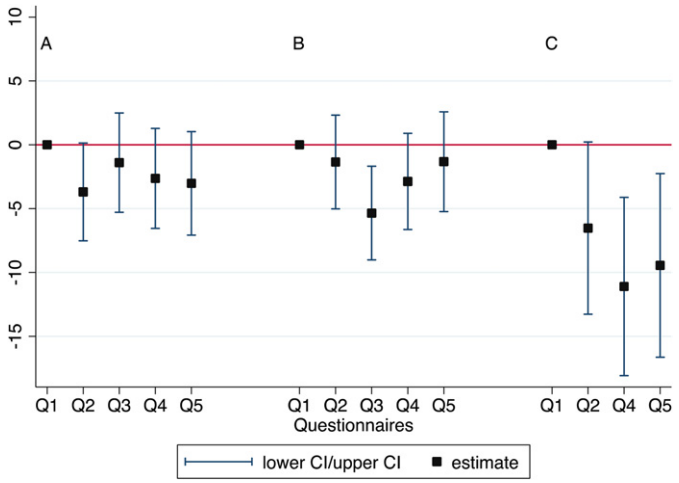

Fig. 3. Change in self-rated level of electromagnetic sensibility/sensitivity, certainty regarding being electromagnetic sensible/sensitive, and in certainty of reacting to EMF within minutes. A: self-rated level of electromagnetic sensibility/sensitivity, B: certainty regarding being electromagnetic sensible/sensitive, C: certainty of reacting to EMF within minutes. CI = 95% confidence intervals; Q1: baseline questionnaire, Q2: questionnaire prior to testing, Q3: questionnaire directly post testing before receiving feedback on personal test results (C was not asked), Q4: follow-up questionnaire at 2 months post testing, Q5: follow-up questionnaire at 4 months post testing. The y-axis shows the mm change on a 100 mm visual analogue scale compared to baseline values and the estimates and confidence intervals were derived using multilevel linear regression, adjusted for age and sex. Note that this analysis disregards randomisation into immediate testing group and waiting group.

average 3.3 and 2.8 symptoms ($p \leq 0.001$). The total severity-attribution score of reported symptoms also declined between baseline and follow-up questionnaires at two and four months ($p = 0.01$), see Fig. 4. Neither for the reduction in symptoms, nor the reduction in the severity-attribution score of reported symptoms did we observe statistically significant interactions with chronicity, motivation to participate or season, indicating no material differences for these outcomes in the respective subgroups (data not shown).

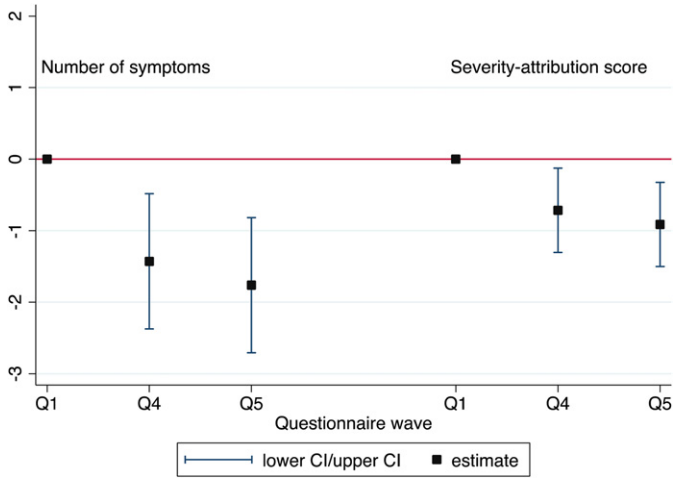

Fig. 4. Change in number of symptoms and in the symptom severity-attribution score. CI = 95% confidence intervals; Q1: baseline questionnaire, Q4: follow-up questionnaire at 2 months, Q5: follow-up questionnaire at 4 months. The y-axis corresponds to change in number of symptoms (left part of graph) and the symptom severity-attribution score (right part of graph) at follow-up compared to at baseline. Coefficients were derived using multilevel linear regression models, adjusted for age and sex. Note that this analysis disregards randomisation into immediate testing group and waiting group, and that symptoms, attribution of symptoms to EMF and severity of symptoms was only asked at baseline and at two and four months of follow-up.

4. Discussion

We performed a double-blind randomised controlled trial with personalised testing of people who reported they could sense when being exposed to EMF within minutes of exposure, in order to test whether subjects were able to identify when they were exposed, and to test if giving immediate feedback on their individual test results would stimulate reconsideration and hence change their self-rated electromagnetic sensibility/sensitivity. Although 40 of 42 participants reported reacting to the exposure in an unblinded test within a few minutes of exposure, during double-blind testing, none of our tested participants was subsequently able to correctly identify when they were being exposed or not better than chance. Testing and feedback on results did not materially change self-rated levels and certainty of electromagnetic sensibility/sensitivity at two and four months post testing compared to at baseline, but participants reported reduced certainty of responding within minutes to EMF and also reported fewer symptoms and lower severity-attribution symptom scores at two and four months compared to at baseline.

4.1. Strength and limitations

Strengths of our study include that we took account of previous criticism of provocation trials and personalised the exposure to what study participants reported reacting to and that we tested them at home without requiring them to travel to a test location. We also confirmed that we had selected the "correct" type of signal by performing an unblinded exposure session first, in which participants could verify that they indeed reacted to the chosen signal.

A limitation of our study was that by performing at-home testing, exposure situations were not as standardised as if we had used controlled exposure conditions in an anechoic laboratory, shielded against influence from the outside. However, although we did not check background exposures at the homes of participants, the expectation would be that adding exposure generated with our units would still generate contrast in exposure between true and sham conditions and we verified our testing environment in the open/unblinded exposure session in which our study participants reported reacting to the applied exposure.

Another limitation relates to the fact that for ethical reasons, we offered all participants testing, so we did not have a true control group to compare our results to. We used immediate and waiting-trial arms to compare if self-reported sensitivity and sensibility to EMF differed depending on whether people had undergone testing or if they had waited, and did not observe any statistically significant group differences between the two arms. Interestingly, VAS ratings were already slightly reduced in all three core questions prior to testing compared to at baseline, indicating an effect of participation in the study as such. For feasibility reasons we did not repeat questions on symptoms in all questionnaire waves, but only at baseline and at two and four months post testing in both trial arms. The analysis on symptoms therefore relates to a before-after analysis, which means that other factors could have played a role: For example, if more participants filled in follow-up questionnaires during the summer, this could have led to a lower symptom reporting compared to filling it in in the winter (Huibers et al, 2010). Adjusting for the season in which the testing was done, however, also did not affect our results (data not shown).

Our participants were not able to correctly identify when being exposed or not. Reaction to exposure during the unblinded exposure may thus have been due to a nocebo effect. It is also conceivable that participants do not react consistently to exposure over time and that within the test series of 10 conditions, possible carry-over effects from previous conditions may have hampered them from being able to sense exposure conditions in subsequent conditions. In that case, one would expect participants to have performed better earlier in the test, but there was no evidence for such an effect (Supplementary Fig. S1).

4.2. Previous studies

While overall previous studies have not provided evidence that persons can sense when being exposed (Röösli et al., 2010), most studies only applied two or three exposure and sham conditions and thus reported electromagnetic sensibility/sensitivity on a group level and not on an individual level. This means that if the proportion of truly electromagnetic sensible persons is low, these persons could have been overlooked in the previous assessments. Of the few studies so far that applied more repeated exposure conditions per individual, there was no evidence of the ability to sense radiofrequency EMF exposure, in line with our study results (Radon and Maschke, 1998; Kwon et al., 2008). For extremely low frequency magnetic field exposure, one study reported that there had been 7 out of 63 participants who were able to detect better than expected by chance to identify when being exposed to a 50-Hz sine field (corresponding to a p-value of 0.04 (Mueller et al., 2002)). Another study reported one person out of 71 who was near-perfect in detecting a 50-Hz sine field applied 20 times in a randomised blinded fashion to the arm, although at a much higher field strength as compared to what we applied in our study (Köteles et al., 2013). Four of our 42 participants selected to be tested with extremely low frequency magnetic fields and these participants were equally not found to be able to correctly identify when exposure was on or off.

After the experiment, we found that study participants materially adjusted neither their level of electromagnetic sensibility/sensitivity nor their certainty of being electromagnetic sensible/sensitive, but reported reduced certainty of reacting to EMF within minutes. Possibly this was related to the study design that targeted short-duration exposures and immediate reactions to the exposure, and not potential longer-term reactions. Participants also reported fewer symptoms, and lower symptom severity-attribution scores two and four months after testing. We have no clear explanation regarding these results. One previous study exposing study participants to 20 repeated exposure conditions of a 50-Hz sine field reported a decrease in self-rated electromagnetic hypersensitivity after testing (Mueller et al., 2002). In this study, change in self-reported hypersensitivity was unrelated to true sensitivity to EMF during the experiment. This is also consistent with another study where participants were provided with feedback on whether they had been able to correctly detect when being exposed, although this feedback was based on just two exposure conditions (Nieto-Hernandez et al., 2008). After their study, 39% of 61 study participants suggested they were willing to reconsider their attribution of symptoms to mobile phone signals, but this was independent of whether or not they had received feedback that they had been correct or incorrect in assigning exposure conditions during the provocation experiment. While symptom reporting appeared to be slightly reduced in the group willing to reconsider attribution, this effect was not statistically significant (Nieto-Hernandez et al., 2008). Our study results are therefore in line with previous results indicating an effect of participation.

An explanation for a reduction in symptoms and in the severity-attribution score could be that participants still considered themselves as electromagnetic sensitive, but also realised they would not react to exposure within minutes of being exposed (Fig. 3). The majority of our participants (93%) preferred to be tested in their usual home environment, indicating that they felt comfortable enough to undergo testing at this location, which would mean that perceived exposure situations would be restricted to when being not at home. An interpretation of our study results could thus be that there was a true effect of participation in the study in reducing symptoms, if possibly short-duration exposure when being away from home no longer triggered an immediate symptom response. An alternative explanation is that, during subsequent questionnaires, participants experienced questionnaire fatigue and thus did not list all symptoms they had experienced during the previous month, which would result in an apparent effect of symptom reduction across questionnaire waves. However, it would be unclear why such questionnaire fatigue would be restricted to symptom reporting.

It should be noted that our study targeted persons who agreed to test their own hypothesis reacting to EMF exposure within a short time frame (minutes). Therefore, our result of a reduction in certainty of reacting within minutes to exposure, and reduced symptom reporting, may not easily be generalizable to all electromagnetic hypersensitive individuals.

5. Conclusions

We found no evidence that subjects who reported being able to respond quickly to EMF exposure and with whom we had verified this in an open exposure session were able to distinguish exposure from sham conditions better than chance. Over four months of follow-up after double-blind testing and providing personal test results, self-reported level and certainty of electromagnetic sensibility/sensitivity did not decrease, but self-reported certainty of responding within minutes to EMF exposure did, as did the number of reported symptoms and symptoms attributed to EMF exposure and weighted by severity. While we cannot prove that this reduction was due to participation in the study, the results indicate a subgroup of persons who profits from participation in a personalised testing procedure.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2016.11.031.

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