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Can exposure to a terrestrial trunked radio (TETRA)-like signal cause symptoms? A randomised double-blind provocation study

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ABSTRACT

Objectives Concerns have been raised about possible health effects from radiofrequency fields pulsing at around 16 Hz. A radio system used by UK police (TETRA) employs signals which pulse at 17.6 Hz. We tested whether exposure to a continuous wave signal at 385.25 MHz or a TETRA-like signal resulted in symptoms among users reporting sensitivity to TETRA compared to users not reporting sensitivity to TETRA.

Methods 60 sensitive and 60 non-sensitive users were exposed to three 50 min conditions: a signal with a 16 Hz component, a continuous wave condition and a sham condition. The mean radiated power for the 16 Hz and continuous wave conditions was 250 mW. The order of conditions was randomised and testing was conducted double-blind. Participants reported the severity of eight symptoms during and after each exposure, their mood state at the end of each exposure, and whether they could tell which sessions involved active signals. The study was registered in advance with the ISRCTN register.

Results Exposure to the continuous wave signal increased ratings of headache in all participants, fatigue in non-sensitive participants and difficulty concentrating in sensitive participants. Paradoxically, it reduced sensations of itching in sensitive participants. These effects were not observed in the condition with 16 Hz pulsing, except for those relating to concentration. Adjusting for multiple comparisons removed most significant effects, but not those relating to itch.

Conclusions The results suggested that exposure to TETRA signals is not responsible for symptoms reported by some users, although exposure to a continuous wave signal may affect symptoms.

Clinical trial number ISRCTN 73321766.

What this paper adds

- Previous systematic reviews have found no causal link between the presence of electromagnetic fields and the reporting of adverse symptoms.
- No studies have examined the effect of signals from a new radio system called Truncked TErrestrial RAdio (TETRA), although some users report symptoms.
- Our study suggests that exposure to TETRA signals does not trigger adverse symptoms.
- Unexpectedly, the results showed that exposure to non-pulsing continuous wave signals could affect symptom occurrence.

INTRODUCTION

Terrestrial trunked radio (TETRA) is a digital mobile radio system in which some of the signal emitted by a user's handset pulses at a frequency of 17.6 Hz.[1] This is close to a frequency that the UK's Independent Expert Group on Mobiles Phones recommended should be avoided if possible. Their recommendation related to "amplitude modulation around 16 Hz" and was based on earlier equivocal evidence of biological effects caused by signals operating at this frequency.[2]

The TETRA system was introduced to the UK police in 2000 as a replacement for their existing analogue radios. Some police officers from the first area to trial the equipment reported experiencing symptoms such as nausea and headaches which they attributed to their use of the radio. As yet, no experimental study has examined the effects of short-term exposure to TETRA handset signals on subjective symptoms. Using a double-blind design we tested whether exposure to a TETRA-like signal causes acute symptoms among regular TETRA users. In order to assess if the pulsing nature of the TETRA signal is important, the effects of exposure to a continuous wave signal of the same mean power and basic frequency were also tested. Finally, we also tested whether any effects of exposure were more noticeable in individuals who had previously attributed symptoms to TETRA than in individuals who had not previously reported such symptoms.

METHODS

Design

We exposed two groups of participants ('sensitive' and 'non-sensitive') to three different conditions ('TETRA-like', 'continuous wave' and 'sham' exposure) in a double-blind within-participants randomised controlled study. Randomisation and blinding was conducted by staff at the Institute of Psychiatry Clinical Trials Unit who were independent from the research team, using a procedure described elsewhere.[3]

Ethics

This study was approved by the South London and Maudsley NHS Trust research ethics committee (reference 04/Q0706/65).

Participants

Volunteers had to be 18 years of age or over and use a TETRA radio at least once a week. Participants were eligible for the sensitive group if they reported experiencing symptoms which they attributed to TETRA and if they reported being at least 70% sure that their radio's signal was to blame. Participants were only included in the sensitive group if these sensations occurred within an hour of radio use and if they occurred when the radio was used near their head. Participants were included in the non-sensitive group if they did not experience symptoms which they attributed to the radio. Participants were excluded if they reported being pregnant, trying to conceive or had any medical or psychological condition which could cause similar symptoms to those examined here. We advertised the study within UK Police Forces using circular emails, notices in police newsletters and intranet sites, and adverts in several police-related magazines and websites.

Exposure equipment

The exposures were delivered by the UK Mobile Telecommunications and Health Research (MTHR) programme's TETRA exposure system.[4] This system produced a mean radiated power of 250 mW for the continuous wave and TETRA-like exposures, resulting in a maximum specific energy absorption rate (SAR) close to the antenna with a value of 1.3 W/kg averaged over 10 g (±30%). The SAR value from the handset body was 0.3 W/kg in TETRA-like and continuous wave mode. For the sham mode, the power was diverted to an internal load in order to provide the same heating and low-frequency magnetic fields as produced by the active modes. Minor leakage of the signal occurred through the antenna in the sham condition, producing a mean SAR of approximately 0.002 W/kg. The TETRA-like signal had a pulsing frequency of approximately 16 Hz. Because of this, the TETRA-like condition produced a peak radiated power of 1 W. The carrier frequency for TETRA-like and continuous wave modes was 385.25 MHz.

Measures

We collected the following background data for both groups: demographic data; the presence of 50 symptoms over the previous month and whether these symptoms were attributed to TETRA; the presence and severity of medically unexplained sensitivities (assessed using a list of possible chemical and electrical symptom triggers including five triggers related to TETRA equipment)[3]; whether participants described themselves as having 'electrosensitivity/sensitivity to electromagnetic fields'; and whether participants had ever experienced symptoms which they attributed to their previous analogue radio system. We also asked participants in the sensitive group: how long they had been sensitive to their TETRA radio; how quickly they usually developed symptoms when using their radio; how long their symptoms usually lasted; how near a handset had to be to affect them; and how much their sensitivity to TETRA affected their ability to work.

Immediately before and at the end of each experimental session participants completed the Positive and Negative Affect Schedule (PANAS).[5] This mood rating scale produces two scores (positive mood and negative mood), each scored from 10 (least emotion) to 50 (most emotion). At several points during the testing sessions, participants assessed whether they were experiencing any of eight symptoms using 11-point numerical scales from 0 (no sensation) to 10 (worst possible sensation). The eight symptoms were: headache; fatigue; dizziness; nausea; sensations of warmth or burning on skin; skin itching, tingling, stinging or numbness; feeling irritable, anxious or depressed; and difficulty concentrating or thinking. Following each exposure session, participants stated whether they thought the handset was emitting a signal or not and how confident they were about this on an 11-point scale from 0 (complete guess) to 100 (100% certain). At the end of the third session, they also stated which session they thought was most likely to have involved a TETRA signal, which one was most likely to have been the sham session, and how confident they were about both answers.

Procedure

We provided written information to those individuals who approached us about the study and conducted a telephone interview in order to assess their suitability. Individuals who met the inclusion criteria were invited to visit our research unit on three occasions. We asked participants to refrain from taking recreational drugs for at least 1 week before each visit and to avoid drinking alcohol for at least 24 h. We also asked them to avoid taking painkillers or other non-essential medication on the day of each visit and to avoid stressful situations or strenuous exercise.

Participants were exposed to one of the three signals (TETRA-like, continuous wave or sham) in each session. Sessions were booked with at least 24 h between them, or longer if a participant reported that they usually took more than 24 h to recover from exposure to TETRA. Sessions took place inside an unshielded room lit by two incandescent table lamps. Each session started with a resting period of 30 min. During this time in the first session, informed written consent was obtained and the background data questionnaire completed. After 30 min, the handset was attached using a headband and positioned so that the antenna was within a few millimetres of the head, above and slightly behind the participant's left ear. Immediately prior to exposure, the participant completed the PANAS and a baseline symptom severity questionnaire assessing the eight symptoms. The handset was then turned on. Symptom severity scales were completed again after 5, 15, 30 and 50 min during the exposure, at which point the PANAS was completed again and the handset then turned off and removed. After another resting period of 30 min, the participant was asked whether he or she thought the radio had emitted a signal and how confident he or she was about this. When not completing our questionnaires, most participants chose to read magazines during the testing sessions. At least 24 h later, the participant completed the symptom scales again over the phone in relation to how they were feeling at that moment. The second and third sessions used the same procedure except for the type of signal emitted. At the end of the third session, participants were asked which of the three sessions they thought was emitting TETRA, which one was sham, and how confident they were about this.

Sample size calculation

The sample size calculation for this study was the same as that performed for a previous study using the same experimental design.[3] This suggested that 60 participants would be required in order to detect a moderate effect size of exposure to TETRA in the sensitive group. However, the distribution of our data (see analyses) led us to change our planned analytical strategy. A subsequent power calculation showed that our new strategy gave us 90% power to detect an absolute increase of 25% or more of participants reporting headache in the continuous wave condition compared with the sham condition, using the 5% significance level.

Analysis

χ^2 Tests and t tests were performed to compare background data between the groups, using SPSS v 15.0.

Although the symptom severity scales offered 11 ordered response categories, participants' responses were highly skewed and over-dispersed and attempts to use analyses based on ordered category models were found to be unstable. We therefore dichotomised each 11-point symptom severity score into a value of symptom absent (score of 0) or present (score of 1 to 10).

We analysed the dichotomised ratings individually using univariate generalised linear mixed-effects models (GLMMs) to account for the correlation between the repeated binary measures per subject. These GLMMs used the adaptive Gaussian Hermite approximation with seven quadrature points to analyse symptom severity over time in the three different conditions.[6] This analysis used version 2.9.2 of R and the lme4 package.[7 8] For each symptom, we first fitted an initial multi-level mixed-effects model which included the following design-related fixed effects: session (first, second or third testing session), baseline symptom rating, within-session time (5, 15, 30 or 50 min), group (sensitive vs non-sensitive) and the interactions between baseline and time, and between group and time. The models also included subject-varying random intercepts and random slopes for session and time and their two-way interaction. This model was then compared with a model that also included eight terms that were related to the experimental exposures, namely two exposure variables ('continuous wave' or 'pulsing'), their two-way interactions with time and with group, and their three-way interactions with both group and time. The interaction terms were used to test whether exposure had a greater effect in one group than the other, and to test whether this difference became more apparent over time. For these second models, dummy variables were set up for exposure, with one dummy variable labelled 'continuous wave' being coded as 1 for continuous wave and 1 for TETRA-like, and the other dummy variable labelled 'pulsing' being coded as 0 for continuous wave and 1 for TETRA-like. Coding the dummy variables in this way allowed us to examine the specific effects of the pulsing within our TETRA-like exposure by controlling for any non-pulsing effects of the signal which will also have been present in our continuous wave condition. In our results, an effect of 'pulsing' therefore indicates a difference between the TETRA and continuous wave conditions. We first assessed whether adding the eight exposure-related terms significantly improved our ability to predict whether or not a participant had experienced a given symptom using likelihood ratio χ^2 tests. For those symptoms in which adding all eight exposure-related terms significantly improved the model, we used a step-down procedure, based on the likelihood ratio χ^2 test to identify which of the eight terms produced the best fitting yet most parsimonious model.

For two symptoms ('fatigue' and 'skin itching, tingling, stinging or numbness') our original models produced false convergence warnings. For these symptoms, we used analyses with a simplified random-effects structure (random intercepts and random slopes only over session) and a more robust optimisation algorithm (Laplacian approximation).

Positive and negative PANAS scores were analysed separately using a similar procedure, with positive scores dichotomised as less than or equal to 30, or more than or equal to 31, and negative scores dichotomised as scores of 10 versus scores of 11 or more. These cut-offs were selected as round numbers close to the median scores. Initial analyses included baseline score, group and session as the explanatory variables. Subsequent analyses then also included the effects of exposure and the interaction between exposure and group.

Scores for the eight symptoms which were recorded at 24 h follow-up were also analysed in this way. We first allocated each participant an overall score of 0 or 1 for each exposure condition to indicate whether they had experienced any of the eight symptoms at follow-up (defined as reporting a score of 1 or more for any of the symptom severity scales). The initial analysis for this outcome included only the group and session terms. The subsequent analysis added in four terms for exposure and the exposure by group interactions; terms relating to within-session time were not relevant for this analysis.

Finally, we tested the ability of participants to discriminate between the sessions during the experiment, and their ability to judge which session was most likely to have been sham and which TETRA, using generalised linear models with a 1/3 logit link, based on the three alternate forced choice procedure (three AFC in the sensR package of Brockhoff and Christensen[9]).

RESULTS

We were contacted by 134 individuals between December 2005 and December 2007 who appeared to be eligible and who gave verbal consent during our screening process. A total of 121 participants attended their first testing session. One participant in the control group could not find a suitable time to attend for her second session and dropped out from the study. All analyses were based on the 120 participants who finished the study. Demographic data are presented in table 1.

The sensitive group reported being sensitive to a significantly higher number of electromagnetic ($p<0.001$) and chemical stimuli ($p=0.009$) than the non-sensitive group (see online supplement). They also reported a significantly higher number of neurophysiological, respiratory, cardiovascular, peripheral-neurological and global symptoms in the past month ($p<0.005$). No participants from the non-sensitive group attributed any symptoms in the past month to their TETRA radio, while the sensitive group attributed a median of 2 (IQR 1–4.75)

Table 1 Demographic information for sensitive and non-sensitive participants and comparison between groups with χ^2 and t tests (n=120)

	Sensitive, n=60	Non-sensitive, n=60	Difference between the groups
Age, mean (SD)	35.6 (7.4)	38.2 (8.0)	t=1.9, 118 df, p=0.06
Sex, male/female (n)	53/7	50/10	χ^2=0.6, 1 df, p=0.43
Marital status, single/married or cohabiting/separated or divorced (n)	13/47/0	17/36/7	χ^2=9.0, 2 df, p=0.01
Ethnicity, white/other (n)	55/5	58/2	χ^2=1.4, 1 df, p=0.24
Educational level, no qualification/secondary/higher education (n)	2/44/14	1/45/14	χ^2=0.3, 2 df, p=0.84
Employment status, full time/part-time/sick leave (n)	56/3/15	55/5/0	χ^2=1.5, 2 df, p=0.47
Police rank, civilian/trained police/higher rank (n)	7/44/9	8/33/19	χ^2=5.2, 2 df, p=0.07

symptoms. The most commonly attributed symptoms were headaches (reported by 86%), fatigue (31%), forgetfulness (23%), loss of concentration (23%) and irritability (22%). None of the participants reported having experienced symptoms with their previous analogue radios. Additional descriptive data about the sensitive participants are available in the online supplement.

Symptoms reported during the study

Continuous wave exposure increased the likelihood of headache, but pulsing prevented this effect from occurring (figure 1; see online data supplement for the full model). Collectively, the eight terms that involved continuous wave and pulsing exposure improved the basic model for headache ratings (LR χ^2=15.6, 8 df, p=0.048). Backward stepwise elimination showed that none of the interaction terms were significant, but only the main effects of continuous wave (p=0.004) and pulsing (p=0.013).

Collectively, the exposure effects significantly improved the basic model for fatigue (LR χ^2=17.9, 8 df, p=0.02). Backward stepwise elimination showed that the three-way interactions were significant (see online data supplement). In detail, non-sensitive participants undergoing continuous wave exposure showed lower early fatigue ratings (intercept: p<0.0001) and a faster increase in these ratings over time (continuous wave×time interaction: p=0.014), but pulsing prevented these effects (intercept: p=0.01; time×pulsing interaction: p=0.003). Sensitive participants showed higher initial ratings of fatigue (p=0.0002), but neither continuous wave exposure nor pulsing affected their rates of increase over time (p=0.29). Thus continuous wave and pulsing had opposite effects on fatigue ratings in non-sensitive participants, but neither form of exposure altered fatigue ratings in sensitive participants. Figure 2 illustrates this complex effect in more detail.

Continuous wave exposure increased the likelihood of 'difficulty concentrating or thinking' in sensitive participants during the exposure (figure 3). Collectively, the eight exposure-related terms improved the basic model (LR χ^2=16.0, 8 df, p=0.04). Backward stepwise elimination showed that the two-way interaction of exposure with sensitivity was significant, with an effect of continuous wave only being observed for the sensitive group (continuous wave×group: p=0.037; see online supplement). Pulsing exposure did not prevent this effect from occurring (p=0.94).

Continuous wave exposure reduced ratings of itching in sensitive participants, but pulsing prevented this effect from occurring (figure 4). Collectively, the eight terms that involved continuous wave or pulsing exposure improved the basic model for itch ratings (LR χ^2=23.7, 8 df, p=0.003). Backward stepwise

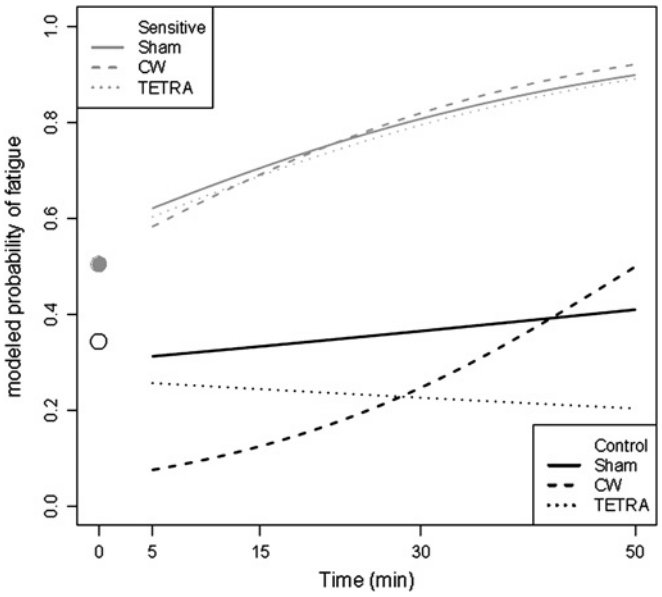

Figure 2 Modelled probability of fatigue occurring during the sham, continuous wave (CW) and TETRA-like exposures. The open circle indicates the baseline for non-sensitive control participants. The closed circle indicates the baseline for sensitive participants.

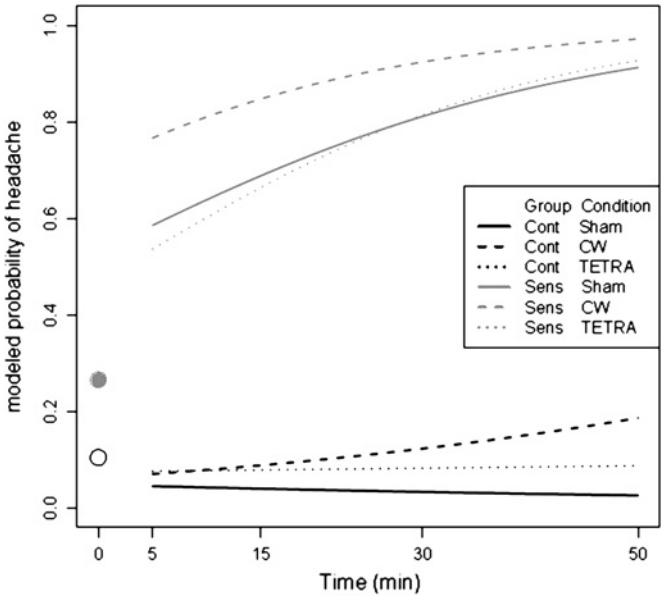

Figure 1 Modelled probability of a headache occurring during the sham, continuous wave (CW) and TETRA-like exposures. The open circle indicates the baseline for non-sensitive control participants. The closed circle indicates the baseline for sensitive participants.

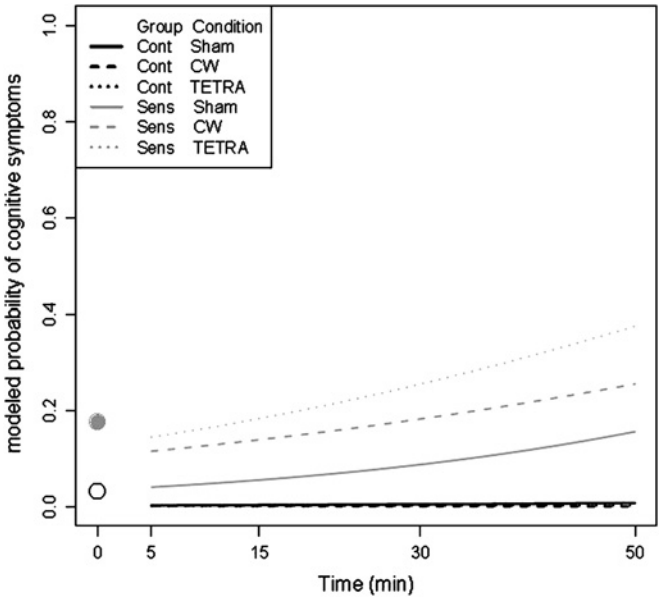

Figure 3 Modelled probability of difficulty concentrating or thinking occurring during the sham, continuous wave (CW) and TETRA-like exposures. The open circle indicates the baseline for non-sensitive control participants. The closed circle indicates the baseline for sensitive participants.

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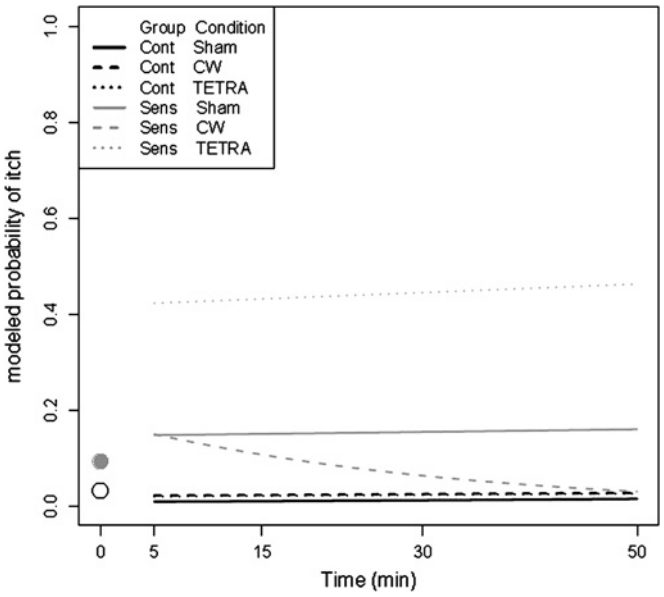

Figure 4 Modelled probability of 'skin itching, tingling, stinging or numbness' occurring during the sham, continuous wave (CW) and TETRA-like exposures. The open circle indicates the baseline for non-sensitive control participants. The closed circle indicates the baseline for sensitive participants.

elimination showed that the two-way interaction of exposure with group was significant (see online data supplement for the full model), because the contrasting effects of exposure on itch ratings in the sensitive group (continuous: p=0.069; pulsing: p=0.009) were absent in the non-sensitive group (continuous: p=0.27; pulsing: p=0.71).

Adding in all eight exposure-related terms did not improve the basic models for the ratings of feeling irritable, anxious or depressed (LR χ^2=5.9, 8 df, p=0.66), nausea (LR χ^2=7.3, 8 df, p=0.51), dizziness (LR χ^2=4.0, 8 df, p=0.86) or sensations of warmth or burning on skin (LR χ^2=14.6, 8 df, p=0.07).

For symptoms reported at 24 h follow-up, continuous wave exposure increased the likelihood of reporting any symptom, while pulsing prevented this effect. Statistically, the four exposure-related terms were significant overall (LR χ^2=10.6, 4 df, p=0.03) with significant main effects of the continuous wave (z=2.3, p=0.02) and pulsing (z=−3.1, p=0.002) conditions.

In order to correct for the use of multiple statistical tests, we adjusted the p values for the nine overall LR χ^2 statistics which related to symptom reporting during the experiment or at 24 h follow-up. This was done using the Simes adjustment.[10] With p values adjusted in this way, adding in exposure-related terms did not significantly improve the models for headache (p=0.09), fatigue (p=0.09), 'difficulty concentrating or thinking' (p=0.09), 'feeling irritable, anxious or depressed' (p=0.74), nausea (p=0.66), dizziness (p=0.86), sensations of warmth or burning (p=0.11) or symptoms recorded at follow-up (p=0.09). Itch, however, still showed a significant overall effect of adding in the exposure-related terms (p=0.03).

Mood reported during the study

Inclusion of exposure-related terms did not affect the model for the negative subscale of the PANAS (LR χ^2=2.8, 4 df, p=0.6). Scores for the positive subscale showed a nearly significant effect (LR χ^2=9.1, 4 df, p=0.06), with pulsing exposure tending to increase the likelihood of a high positive mood score, but only in the non-sensitive group (group×pulsing: p=0.02).

Discrimination between the presence and absence of signals

We found no evidence that participants could detect the presence of a signal during each session or that they could tell which sessions were most likely to have been sham and which were most likely to have been TETRA (see online data supplement for details). Neither sensitive nor non-sensitive participants could discriminate between the exposures during the experiment (non-sensitive: p=0.84; sensitive: p=0.30), nor could they tell which session was most likely to have been sham (non-sensitive: p=0.4; sensitive: p=0.7) or which was most likely to have been TETRA (non-sensitive: p=0.7; sensitive: p=0.55).

DISCUSSION

This study found no robust evidence that a TETRA-like signal with a mean SAR of 1.3 W/kg could affect symptom reporting. Instead, our continuous wave signal tended to reduce the symptom relating to 'skin itching, tingling, stinging and numbness', while the inclusion of a 16 Hz component prevented this reduction.

This finding was unexpected, as suggestions that 16 Hz signals might be more biologically active than other forms of signal were the original reason for us carrying out this study.[1] In general, concern about radiofrequency fields has typically focused on pulsing signals.[11 12] It is unclear why the continuous wave signal in our study showed a larger effect. One possibility is that the findings reflect the different peak radiated powers used in our two experimental exposures: while the mean power of both was the same, the pulsing nature of our TETRA-like signal meant that its peak power was four times greater than that for the continuous wave signal. However, why any impact on subjective symptoms might be more observable for exposures with a lower peak power is unclear.

That our continuous wave signal produced any effect on symptom occurrence was itself unexpected. Although exposure to radiofrequency fields has been associated with symptom occurrence in several surveys and case studies,[13 14] experimental provocation studies have repeatedly failed to produce replicable evidence showing that radiofrequency fields are the cause of these symptoms.[15–17] This includes one recent experimental provocation study which identified no adverse effects from TETRA-like base station signals.[18] While the majority of previous studies have focused on pulsed signals of the type used in mobile phone systems, those that have included continuous wave signals have also typically failed to identify any effects on subjective well-being or related parameters.[15–17]

Our observation that the effect of continuous wave on skin sensations only occurred in people with self-reported sensitivity to TETRA also contradicts previous studies in this area, which have typically failed to identify any sensitivity to electromagnetic fields among individuals who report being sensitive to them.[15–17] However, our findings were not consistent with the reports of our sensitive participants. First, the direction of the effect that we observed was contrary to that typically reported by people who report sensitivity to electromagnetic fields, with exposure decreasing rather than increasing the likelihood of skin symptoms. Second, while our participants were recruited on the basis of their apparent sensitivity to TETRA, it was continuous wave that appeared to affect them. Third, it was notable that an effect was only observable for skin sensations, whereas our participants reported headache to be the symptom that they most commonly experienced when using TETRA in everyday life. While our results suggest that some people may be sensitive to electromagnetic fields, it appears that not all of the symptoms reported by such people occur as a direct consequence of exposure.

Methodological limitations

Several methodological caveats should be considered in relation to our study. First, the power of our analyses was lower than we had hoped. Although we would still have been able to detect a large effect of exposure, similar to the size of effect reported by our sensitive participants in their everyday life, smaller differences, which might still have been of clinical and theoretical relevance, may have been missed.

Second, our study included analyses of several symptoms and it was necessary to adjust for these multiple comparisons when assessing the significance of our results. We choose a Simes adjustment in order to reduce the chance of reporting a spurious positive finding. Although less conservative than other Bonferroni-type corrections, the Simes adjustment still reduces the possibility of false positive results at the possible expense of producing false negatives.[10 19] Different adjustments for multiple comparisons, for example estimation of the false discovery rate, may control false positives at the expense of allowing more false negatives. If we had made no adjustment, or used a false discovery rate adjustment, then our results would have suggested that in addition to its effects on skin sensations, continuous wave exposure can trigger headaches, fatigue and difficulty concentrating or thinking, effects which were still detectable at 24 h follow-up and which were largely prevented by the inclusion of a 16 Hz pulsing component.

A third limitation is that our sham condition was not zero exposure. As with a previous experiment by our group, leakage from the exposure equipment of a continuous wave signal occurred during the sham sessions.[3] However, this leakage was at a very low level, with a mean power 650 times lower than that in the other exposures. It seems unlikely that this would have prevented us from detecting a difference between the sham and continuous wave exposures.

Conclusions

Despite these methodological caveats, our study identified a significant effect of continuous wave exposure on skin sensations in participants who reported sensitivity to TETRA. This effect that was not apparent during exposure to a TETRA-like signal. Attempts to replicate these unexpected findings would be beneficial. In the meantime, our results should be relatively reassuring for users of TETRA radios. Not only did our TETRA-like exposure have no specific adverse effects in comparison to continuous wave, if anything inclusion of a 16 Hz component appeared to make our signal less biologically active.

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Competing interests None.

Ethics approval This study was conducted with the approval of the South London and Maudsley NHS Trust Research Ethics Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1. **Advisory Group on Non-Ionising Radiation.** *Possible health effects from terrestrial trunked radio (TETRA): report of an advisory group on non-ionising radiation*. Didcot, Oxon: National Radiological Protection Board, 2001.
2. **Independent Expert Group on Mobile Phones.** *Mobile phone and health. Report of an independent expert group on mobile phones (Chairman, Sir William Stewart)*. Chilton: National Radiological Protection Board, 2000.
3. **Rubin GJ,** Hahn G, Everitt B, *et al*. Are some people sensitive to mobile phone signals? A within-participants, double-blind, randomised provocation study. *BMJ* 2006;**332**:886–9.
4. http://www.mcluk.org/_MTHR_exposure_systems (accessed Jan 2010).
5. **Watson D,** Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Pers Soc Psychol* 1988;**54**:1063–70.
6. **Pinheiro JC,** Bates DM. Approximations to the log-likelihood function in the nonlinear mixed-effects model. *J Comput Graph Stat* 1995;**4**:12–35.
7. **R Core Development Team.** *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. Vienna: R Foundation for Statistical Computing, 2008.
8. **Bates D,** Maechler M, Dai B. *lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-28*. http://lme4.r-forge.r-project.org (accessed Nov 2009).
9. **Brockhoff PB,** Christensen RHB. Thurstonian models for sensory discrimination tests as generalized linear models. *Food Qual Prefer* 2008;**21**:330–8.
10. **Simes RJ.** An improved Bonferroni procedure for multiple tests of significance. *Biometrika* 1986;**73**:751–4.
11. **Huber R,** Treyer V, Borbely AA, *et al*. Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. *J Sleep Res* 2002;**11**:289–95.
12. **Regel SJ,** Gottselig JM, Schuderer J, *et al*. Pulsed radio frequency radiation affects cognitive performance and the waking electroencephalogram. *Neuroreport* 2007;**18**:803–7.
13. **Hocking B.** Preliminary report: symptoms associated with mobile phone use. *Occup Med* 1998;**48**:357–60.
14. **Oftedal G,** Wilen J, Sandstrom M, *et al*. Symptoms experienced in connection with mobile phone use. *Occup Med* 2000;**50**:237–5.
15. **Roosli M.** Radiofrequency electromagnetic field exposure and non-specific symptoms of ill health: A systematic review. *Environ Res* 2008;**107**:277–87.
16. **Rubin GJ,** Das Munshi J, Wessely S. Electromagnetic hypersensitivity: A systematic review of provocation studies. *Psychosom Med* 2005;**67**:224–32.
17. **Rubin GJ,** Nieto-Hernandez R, Wessely S. Idiopathic environmental intolerance attributed to electromagnetic fields (formerly 'electromagnetic hypersensitivity'): an updated systematic review of provocation studies. *Bioelectromagnetics* 2010;**31**:1–11.
18. **Wallace D,** Eltiti S, Ridgewell A, *et al*. Do TETRA (Airwave) base station signals have a short-term impact on health and well-being? A randomized double-blind provocation study. *Environ Health Perspect* 2010;**118**:735–41.
19. **Rodland EA.** Simes' procedure is 'valid on average'. *Biometrika* 2006;**93**:742–6.