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Acute Exposure to Terrestrial Trunked Radio (TETRA) has effects on the electroencephalogram and electrocardiogram, consistent with vagal nerve stimulation

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ABSTRACT

Background: Terrestrial Trunked Radio (TETRA) is a telecommunications system widely used by police and emergency services around the world. The Stewart Report on mobile telephony and health raised questions about possible health effects associated with TETRA signals. This study investigates possible effects of TETRA signals on the electroencephalogram and electrocardiogram in human volunteers.
Methods: Blinded randomized provocation study with a standardized TETRA signal or sham exposure. In the first of two experiments, police officers had a TETRA set placed first against the left temple and then the upper-left quadrant of the chest and the electroencephalogram was recorded during rest and active cognitive processing. In the second experiment, volunteers were subject to chest exposure of TETRA whilst their electroencephalogram and heart rate variability derived from the electrocardiogram were recorded.
Results: In the first experiment, we found that exposure to TETRA had consistent neurophysiological effects on the electroencephalogram, but only during chest exposure, in a pattern suggestive of vagal nerve stimulation. In the second experiment, we observed changes in heart rate variability during exposure to TETRA but the electroencephalogram effects were not replicated.
Conclusions: Observed effects of exposure to TETRA signals on the electroencephalogram (first experiment) and electrocardiogram are consistent with vagal nerve stimulation in the chest by TETRA. However given the small effect on heart rate variability and the lack of consistency on the electroencephalogram, it seems unlikely that this will have a significant impact on health. Long-term monitoring of the health of the police force in relation to TETRA use is on-going.

1. Introduction

Terrestrial Trunked Radio (TETRA) is an open standard telecommunications system for private mobile radios used by the emergency services, utility companies and the military in more than 100 countries. TETRA employs time division multiplexing such that the radio frequency (RF) signal (380–395 MHz) is transmitted in a series of bursts (timeslots) with a pulse rate of 17.6 Hz (Challis, 2007; MTHR, 2007). This pulsing may induce an extremely low frequency (ELF) modulation of the magnetic field at 17.6 Hz in addition to, and synchronized with, the pulse-modulated RF electromagnetic fields (EMF).

The UK's Independent Expert Group on Mobile Phones (Stewart Report) concluded in 2000 that '*…as a precautionary measure, amplitude modulation around 16 Hz should be avoided, if possible, in future developments in signal coding*' (IEGMP, 2000). This recommendation was based largely on the results of a study which claimed that RF signals pulsed at around 16 Hz had an effect on calcium efflux from cells (Bawin et al. 1975), though later and

Abbreviations: TETRA, Terrestrial Trunked Radio; ELF, extremely low frequency; EMF, electromagnetic fields; EEG, electroencephalogram; EKG, electrocardiogram; ERPs, event-related potentials; HRV, heart rate variability; SAR, specific absorption rate; ABT, Attentional Blink Task; SART, Sustained Attention to Response Task; VNS, vagal nerve stimulation

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better designed studies using live tissue failed to confirm this finding (MTHR, 2007; Green et al., 2006; NRPB, 2001). From 2001, TETRA was introduced in police forces across the UK. To address the concerns raised by the Stewart Report, in 2003 the UK Home Office commissioned i) the Airwave Health Monitoring Study (Airwave is the commercial name of the TETRA-based digital telecommunications system adopted by the police forces in the UK), an epidemiological (cohort) study into the possible long-term health effects of TETRA (Elliott et al., 2014), and ii) investigation of possible acute effects by comparing effects of TETRA emissions and sham exposure in a blinded randomized provocation study.

We report here the results of the provocation study. This was designed initially (Experiment 1) to investigate whether emissions from TETRA handsets may produce detectable effects on the electroencephalogram (EEG). The EEG measures the brain's naturally occurring, spontaneous, electrical oscillations, which occur at frequencies that overlap the pulsing rate of TETRA. It was therefore hypothesized that the EEG would provide a particularly sensitive test of any neurophysiological effects of TETRA. Based on the results of Experiment 1, we hypothesized that TETRA-RF might have an effect on the vagal nerve and for this reason the study was later extended to include possible effects on heart rate variability (HRV) measured by the electrocardiogram (EKG).

2. Materials and methods

We conducted two experiments. The first studied the effects of TETRA signals on the EEG with placement of the radio against the head and left-side of the chest (Experiment 1). We then included simultaneous recording of the EEG and the EKG, focusing only on the chest placement (Experiment 2).

2.1. Participants

The first sample (Experiment 1) comprised 164 police officers who had joined the Airwave Health Monitoring Study (Elliott et al., 2014), including 107 officers who reported health symptoms they attributed to TETRA. Paid leave was provided by the police force and participants had their expenses paid. The second sample (Experiment 2) comprised 60 volunteers recruited by advertisement and paid £25 for their time. The study was conducted in accordance with the Declaration of Helsinki. All participants gave individual informed consent.

2.2. TETRA exposure system

2.2.1. Experiment 1

TETRA was generated by a radio system that had been especially commissioned by the UK's Mobile Telecommunications Health Research (MTHR) programme (Barker et al., 2007; Butler. 2005; Nieto-Hernandez et al., 2011; Smith, 2007). The radios were designed to transmit in the TETRA range (390–400 MHz) and were calibrated to give a peak specific absorption rate (SAR) of 1.3 $Wkg^{-1} \pm 30\%$ averaged over 10 g, in TETRA mode for head exposure (MTHR, 2001). SAR for chest exposure was not available. We previously showed that TETRA could interfere with the EEG recording system by inducing an electronic artefact at 17.6 Hz and higher harmonics, seen in both human and phantom head recordings (Fouquet et al., 2013). Despite extensive shielding, TETRA interference continued to be found in $\sim$2% of the channels.

2.2.2. Experiment 2

The MTHR radios were no longer available so TETRA was generated using a specially commissioned radio developed by the National Physical Laboratory that transmitted at 381 MHz (just outside the TETRA range to reduce interference with other TETRA users) (MTHR, 2001) and was calibrated to give a peak head SAR of 1.35 $Wkg^{-1} \pm 22\%$ averaged over 10 g and a peak body SAR of 1.0 $Wkg^{-1} \pm 22\%$ averaged over 10 g in TETRA mode (Loader, 2013).

In both experiments, maximum SAR was generated close to the antenna and the distribution of SAR in the head from commercially available TETRA handsets is given in Dimbylow et al. (2003) and for the MTHR handsets in National Physics Laboratory (2013).

2.3. Electroencephalogram

2.3.1. Experiment 1

EEG was recorded from 28 scalp electrodes (see Supplementary Fig. 1a) using a Neuroscan Synamps-II amplifier (Compumedics Neuroscan, USA). EEG was recorded in the resting state (Eyes Closed) and during performance of the Attentional Blink Task (ABT) and Sustained Attention to Response Task (SART) (see Supplementary Material). Channels showing TETRA interference were identified using an automatic algorithm (Fouquet et al., 2013), affecting approximately 2% of channels for head exposure (none for chest exposure); for these channels, data were imputed by interpolation using a weighted average of the nearest four channels. This affected just under one third of the sample (53/164). Participant data were excluded if insufficient artefact-free EEG recordings were available or because of aberrant performance on the tasks leaving 156 (95%) participants for the analyses of the EEG amplitude spectra, 151 (92%) for the SART and 146 (89%) for the ABT.

2.3.2. Experiment 2

EEG was recorded from 21 scalp electrodes (see Supplementary Fig. 1b, which shows the electrode positions for Experiment 2), using a Galileo NT system (EBNeuro, Florence, Italy), during two rest conditions (Eyes Closed and Eyes Open) and during performance of the SART. Data from three people were corrupted due to a failure in the storage medium leaving a total of 57 people for the EEG and HRV analyses. TETRA interference was visible on the EEG recordings for 8 participants and it became apparent following spectral analysis for a further 6, thus un-blinding the experimenters in 14/57 (25%) of the sample. In these cases, data imputation was used for all conditions whether or not they showed evidence of artefact. As both un-blinding and data imputation might bias results, all EEG analyses were performed on the full sample and on the subset of 43 individuals for whom no data were imputed.

EEG data preparation was performed in BESA ver. 5.1.8 (BESA, 2014) and the spectral analysis in MatLab ver. 2014a (MatLab, 2014a). Two bipolar polygraphic channels were used to record vertical and horizontal eye movements. Electro-oculographic artefact correction was performed using Schlogl's algorithm (Schlogl et al., 2007) in Experiment 1 and principal component analysis in BESA ver. 5.3 (Ille et al., 2002) in Experiment 2. Impedances (maintained below 5 kΩ) were measured at the beginning of each recording period using an impedance meter. Data were divided into short epochs; values outside the range $\pm$ 100 μV were treated as artefact and excluded from further analysis. EEG from the Eyes Closed baseline recordings was segmented into epochs of 2.048 ms, de-trended and subjected to multi-taper fast Fourier transform (Percival and Walden, 1993) with time-half bandwidth product = 4 (MatLab, 2014a, 2014b) and average amplitudes in the 0.5–45 Hz range estimated in 0.5 Hz intervals. For event-related potentials (ERPs), EEG data for the ABT were segmented into epochs from −50 ms to +1550 ms around the 1st target stimulus. For the SART, segmentation was −50 ms to +800 ms around the stimulus presentation. In both cases, data were baseline corrected