Environment International 86 (2016) 75–83

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Full length article

Do car-mounted mobile measurements used for radio-frequency spectrum regulation have an application for exposure assessments in epidemiological studies?

John F.B. Bolte [a,*], Myron Maslanyj [b], Darren Addison [b], Terry Mee [b], Jos Kamer [c], Loek Colussi [c]

[a] Centre for Sustainability, Environment and Health, National Institute for Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands
[b] Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Chilton, Didcot, Oxon OX11 0RQ, United Kingdom
[c] Radiocommunications Agency Netherlands, Piet Mondriaanlaan 54, 3812GV Amersfoort, The Netherlands

ARTICLE INFO

Article history:
Received 23 March 2015
Received in revised form 20 August 2015
Accepted 29 September 2015
Available online 3 November 2015

Keywords:
Radiofrequency electromagnetic field
RF EMF
Personal exposure meters
Exposimeters
Mobile measurement
Environmental exposure
Epidemiology

ABSTRACT

Knowing the spatial and temporal trends in environmental exposure to radiofrequency electromagnetic fields is important in studies investigating whether there are associated health effects on humans and ecological effects on plants and animals. The main objective of this study is to assess whether the RFeye car-mounted mobile measurement system used for radio frequency spectrum monitoring in The Netherlands and the United Kingdom could be of value in assessing exposure over large areas as an alternative to measuring exposure with personal exposure meters or using complex modelling techniques. We evaluated the responses of various body-worn personal exposure meters in comparison with the mobile measurement system for spectrum monitoring. The comparison was restricted to downlink mobile communication in the GSM900 and GSM1800 frequency bands. Repeated measurements were performed in three areas in Cambridge, United Kingdom and in three areas in Amersfoort, The Netherlands. We found that exposure assessments through the car-mounted measurements are at least of similar quality to exposure modelling and better than the body worn exposimeter data due to the absence of the shielding effect. The main conclusion is that the mobile measurements provide an efficient and low cost alternative particularly in mapping large areas.

1. Introduction

It is recognized widely that exposure to radiofrequency electromagnetic fields (RF EMF) above certain established guideline limits is likely to cause adverse health effects due to heating (ICNIRP, 1998). These limits are exceeded only in relatively rare situations, for instance in certain occupational settings, and the exposures normally encountered in everyday life tend to be much lower, representing only a small fraction of the guideline limits. This said, there is continuing concern that adverse health effects, such as cancer (Baan et al., 2011; IARC, 2013) and various non-specific physical symptoms (Baliatsas et al., 2012), may occur due to long-term exposure at the low levels encountered in the every-day environment. In a wider context, ecological effects on flora and fauna may be associated with ambient levels of RF EMF (Cucurachi et al., 2013).

With the rapid proliferation of new wireless technologies in society, there is a need to develop efficient and accurate methods to quantify exposure and the demand for high quality exposure data continues to grow (Dürrenberger et al., 2014). National measurement surveys over the past few years, using personal exposure meters or exposimeters, show that exposure differs not only between countries (Joseph et al., 2012; Gajšek et al., 2015), but also is tending to increase over time (Tomitsch and Dechant, 2015). This increase is considered to be due to application of wireless technologies, such as LTE, Wi-Fi, and also due to the change in behaviour of the population (e.g. spending more time on social media on smart phones). Knowing the spatial and temporal trends in environmental exposure provides an opportunity to extend the evidence base for studying potential health effects on humans, plants and animals.

Though exposimeters will give a good estimate of exposure for the small groups of people wearing them, they tend to have limited applicability in investigating spatial and temporal trends over large, geographical areas. In recent years, exposure modelling of mobile phone base station exposure has been pioneered as a technique (Neitzke et al., 2007; Bürgi et al., 2008, 2010; Beekhuizen et al., 2013, 2014). Recently, in Sweden (Estenberg and Augustsson, 2014) and the United States of America (Tell and Kavet, 2014), mobile measurement systems mounted on cars have also been tested for exposure studies. However, the latter are not so much used for specific area mapping but for investigating spatial trends over large areas or countries.

The radiocommunications agencies of The Netherlands and the United Kingdom use a mobile measurement system but with the

* Corresponding author.
E-mail addresses: John.Bolte@rivm.nl (J.F.B. Bolte), Myron.Maslanyj@phe.gov.uk (M. Maslanyj), Darren.Addison@phe.gov.uk (D. Addison), Terry.Mee@phe.gov.uk (T. Mee), Jos.Kamer@agentschaptelecom.nl (J. Kamer), Loek.Colussi@agentschaptelecom.nl (L. Colussi).

http://dx.doi.org/10.1016/j.envint.2015.09.024
0160-4120/

purpose of spectrum regulation (CRFS Ltd., 2009; Radiocommunications Agency Netherlands, 2014; Schiphorst and Slump, 2010). In The Netherlands, most main roads and the larger cities are covered annually, thus providing a huge data set that may be of value in epidemiological research.

The main objective of this study is to assess whether the RFeye car-mounted measurement system, originally built for radio frequency spectrum monitoring, could be used in human health epidemiological studies or ecological studies on flora and fauna. The study compares findings from the mobile measurement system with data recorded using various personal exposure meters, and ranks the results by area type in two different cities. Also, comparisons are made with other mobile measurement methods and an exposure modelling method.

2. Materials and methods

We evaluated the responses of various personal exposure meters, against measurements made for spectrum monitoring with the RFeye car-mounted mobile measurement system. The comparison was restricted to two broadband frequency bands for downlink, from base station to cell phone, mobile communication: GSM (aka GSM900) (925–960 MHz), and DCS (aka GSM1800) (1805–1880 MHz). Repeated measurements were performed in three areas in Cambridge, United Kingdom and in three areas in Amersfoort, The Netherlands. The itinerary was to follow a closed loop for the three areas in Cambridge. In Amersfoort only one itinerary was a closed loop and the other two were part circles. All itineraries were driven both in a clockwise (CW) and a counter-clockwise (CCW) direction. In this way, signals likely to be shielded driving one way were unlikely to be shielded driving the other direction. The areas were chosen to be typically representative of the cities and for possible contrasts in exposure. The itineraries through the areas were chosen such that they reflected the type of area of interest and to ensure an approximate velocity of 30 km/h was attainable on the roads, with a maximum of 50 km/h.

2.1. Measurement equipment and calibration

Measurements were made with EME Spy versions 120, 121, and 140 (Satimo, Cortaboef, France) personal exposure meters, also known as exposimeters, that can be worn on the body. Their detection limit is 0.05 V/m (0.0066313 mW/m^2) for the EME Spy 120 and 121 and 0.005 V/m (0.000066313 mW/m^2) for the EME Spy 140. The EME 121 Spies were calibrated in an anechoic room to determine multiplicative calibration correction factors. They measured every 4th second. If a measurement was at or below the detection level it was set to 0 mW/m^2 for calculations of the mean.

The RFeye car-mounted measurement system consists of two sets of measurement devices, one on the left (RFeye-left) and one on the right (RFeye-right) side of the roof. Each set consists of an antenna mounted on the rooftop of a car, connected to an RFeye measurement unit (CRFS Ltd., Cambridge, UK) consisting of an integrated spectrum analyser, a GPS tracker and a data storage facility.

As the car-mounted measurement system had been designed for radio frequency spectrum monitoring and not for measurement of actual field strength, it was necessary to calibrate the antenna system for the measurements. We applied a multiplicative k-factor to the measurements, which compensates for the reflections from the roof of the car. Two different k-factors were determined: one for of the RFeye-left antenna and one for the RFeye-right. The k-factors were determined from measurements at the Open Area Test Site (OATS) in Leusden, The Netherlands. The response of the RFeye system was determined with the car in four different directions (front, right, rear and left) with respect to a source that transmitted a signal at the mid-frequencies for GSM-downlink, DCS-downlink: 940 MHz and 1840 MHz. The signal strength was measured at the connector of the antenna by a calibrated spectrum analyser. This value was compared (RF substitution method) with the response of a calibrated Rohde & Schwarz HE200 measurement antenna and spectrum analyser which measured the response at the position of the rotation Z-axis of the car, with the car not present. The RFeye antennas were positioned the same as during the surveys in Amersfoort and Cambridge.

The RFeye performed 8 full sweeps every 2 s, over a range from 10 MHz to 6 GHz: from 10 to 500 MHz in 20 kHz bins, from 500 MHz to 2 GHz in 100 kHz bins and from 2 to 6 GHz in 200 kHz bins. Both RFeyes were set to record in standard instantaneous peak mode as used by the Radiocommunications Agency (RCA) during spectrum regulation measurements. According to CRFS, this means that for every bin it retains the maximum value out of the 8 sweeps, thus always overestimating, at any particular position, the average power density of the signal, which is subject to transient increases and decreases in strength over time. Further, instantaneous peak will tend to underestimate all signals for which the peak amplitude of the waveform divided by the RMS value of the waveform is larger than 1, such as LTE. The GSM and DCS measurements acquired in these surveys, though, are correctly represented as LTE and UMTS were not in use in the 900 and 1800 MHz bands at the time of the surveys. If the standard settings for the RFeye were to be optimized for measuring average signal envelopes, instead of “instantaneous peak”, then all other protocols where the peak-to-average ratio's deviate from 0 dB, such as UMTS CDMA and LTE, would also be monitored properly.

The data were recorded using a spectrum analysis Hamming window with a window factor of 2.44. For comparison, two EME Spy 121s were mounted on the rooftop, blue sides facing outwards.

2.2. Cambridge

The first measurement survey was performed in Cambridge, in typical residential, industrial and city areas during the period 14th–16th May 2013 (Fig. 1a). The loop in each area was repeated in CW and CCW directions over two consecutive days to provide a total of four loops per area. In Cambridge the routes were also repeated by a cyclist carrying a GPS logger, two Satimo EME Spy 121 exposimeters, one on the left hip (121-left-hip) and one on the right (121-right-hip), and an EME Spy 120 and an EME Spy 140 in a backpack (120-backpack and 140-backpack)(Fig. 2). The cyclist followed the car-mounted measurement system, which kept a steady speed, never exceeding 30 km/h.

2.3. Amersfoort

The measurement survey in Amersfoort was on 22nd October 2013. Fig. 1b shows the areas in Amersfoort: a mixed office–residential area: Isselt; a typical residential area: Soesterkwartier; and the inner city area. The route around the Soesterkwartier was a closed loop repeated in CW and CCW, the routes in Isselt and the inner city area though not closed were repeated in CW and CCW direction. There was no cyclist on this survey, and the measurements were made solely by the systems mounted on the rooftop: one RFeye system and two EME Spy 121s (121-left-rooftop facing left and 121-right-rooftop facing right).

2.4. Analysis

To smooth out the variability due to changing speed and stops, for each area the measurements over the two CW and two CCW loops were transformed to power density and binned in tiles of 35 × 35 metres (m) over the ideal loop through the middle of the street. A speed of 30 km/h and a sampling interval of 4 s for the EME Spy mean that each tile has at least one measurement. The arithmetic mean per tile was chosen to represent the power density at the centre of that tile. As in the most extreme case the shadowing from the body may be