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Use of portable exposimeters to monitor radiofrequency electromagnetic field exposure in the everyday environment

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ABSTRACT

Background: Spatial and temporal distribution of radiofrequency electromagnetic field (RF-EMF) levels in the environment is highly heterogeneous. It is thus not entirely clear how to monitor spatial variability and temporal trends of RF-EMF exposure levels in the environment in a representative and efficient manner. The aim of this study was to test a monitoring protocol for RF-EMF measurements in public areas using portable devices.
Methods: Using the ExpoM-RF devices mounted on a backpack, we have conducted RF-EMF measurements by walking through 51 different outdoor microenvironments from 20 different municipalities in Switzerland: 5 different city centers, 5 central residential areas, 5 non-central residential areas, 15 rural residential areas, 15 rural centers and 6 industrial areas. Measurements in public transport (buses, trains, trams) were collected when traveling between the areas. Measurements were conducted between 25th March and 11th July 2014. In order to evaluate spatial representativity within one microenvironment, we measured two crossing paths of about 1 km in length in each microenvironment. To evaluate repeatability, measurements in each microenvironment were repeated after two to four months on the same paths.
Results: Mean RF-EMF exposure (sum of 15 main frequency bands between 87.5 and 5,875 MHz) was 0.53 V/m in industrial zones, 0.47 V/m in city centers, 0.32 V/m in central residential areas, 0.25 V/m non-central residential areas, 0.23 V/m in rural centers and rural residential areas, 0.69 V/m in trams, 0.46 V/m in trains and 0.39 V/m in buses. Major exposure contribution at outdoor locations was from mobile phone base stations (> 80% for all outdoor areas with respect to the power density scale). Temporal correlation between first and second measurement of each area was high: 0.89 for total RF-EMF, 0.90 for all five mobile phone downlink bands combined, 0.51 for all five uplink bands combined and 0.79 for broadcasting. Spearman correlation between arithmetic mean values of the first path compared to arithmetic mean of the second path within the same microenvironment was 0.75 for total RF-EMF, 0.76 for all five mobile phone downlink bands combined, 0.55 for all five uplink bands combined and 0.85 for broadcasting (FM and DVB-T).
Conclusions: This study demonstrates that microenvironmental surveys using a portable device yields highly repeatable measurements, which allows monitoring time trends of RF-EMF exposure over an extended time period of several years and to compare exposure levels between different types of microenvironments.

1. Introduction

Advancement in wireless communication technology has been rapid in the last two decades and as a result the exposure pattern to radiofrequency (RF) electromagnetic field (EMF) has changed in the everyday environment significantly (Frei et al., 2009b; Neubauer et al., 2007; Röösli et al., 2010; Tomitsch et al., 2010;

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Urbinello et al., 2014b). This pattern will further continue to change in the future. According to the most recent update from the International Telecommunication Union (ITU), the number of mobile phone subscribers has reached more than 7.0 billion in 2015 which continues to increase in the coming years (ICT Facts and Figures, 2015). The impact of this increment on the RF-EMF exposure situation in the everyday environment is unknown.

Consequently, the World Health Organization (WHO) has recommended the quantification of personal RF-EMF exposure and identification of the determinants of exposure in the general population as a priority in their research agenda (World Health Organization, 2010). However, very little has been done to monitor EMF exposure situation of the population or specific environments. This is mainly due to the complex nature of exposure quantification and high temporal and spatial variability of RF-EMF levels in the environment (Bornkessel et al., 2007; Frei et al., 2009a; Joseph et al., 2008; Röösli et al., 2010).

Several methods have been used for exposure assessment and monitoring of RF-EMF levels in the environment; propagation models have been used to predict the distribution of RF-EMF exposure emitted from fixed site transmitters. Various different types of propagation model have been used in different contexts like network planning and site selection or epidemiological studies (Beekhuizen et al., 2014; Bürgi et al., 2010, 2008; Neitzke et al., 2007). Such models are attractive, particularly because exposure can be assessed without the involvement of study participants which minimizes information and selection bias. However, such models fail to map exposure situation of individual behavior and of sources where input data are not available such as WLAN hotspots or other people's wireless devices.

Another option for RF-EMF monitoring is conducting spot measurements (e.g. Berg-Beckhoff et al., 2008, Tomitsch et al., 2010). Spot measurements are conducted at one point-in-time at specific places with stationary devices. The advantage of such measurements is the possibility of strict adherence to the measurement protocol and the use of sophisticated measurement devices. However, this method is limited in the spatial resolution and in terms of population exposure; it does not take into account the behavior of the people. Access to private places (homes) may be difficult to obtain, and selection bias is of concern for representative sampling, which may be aimed in a monitoring study. Additional bias could be introduced by the selection of the exact measurement place in a given setting. Analysis of temporal variability may be hampered by inaccuracy of the location of repeated spot measurements because RF-EMF may vary within a few centimeters.

Personal measurements of RF-EMF exposure are conducted using portable devices (Blas et al., 2007; Bolte and Eikelboom, 2012; Frei et al., 2009b; Iskra et al., 2010; Joseph et al., 2010, 2008; Knafl et al., 2008; Neubauer et al., 2007; Radon et al., 2006; Röösli et al., 2010; Thuróczy et al., 2008; Urbinello and Röösli, 2013; Urbinello et al., 2014a, 2014a, 2014b). Being small enough in size, exposimeters are carried by the participants and thus measure the exposure during their daily life activities. As a result, exposimeters have been used to investigate the predictors of personal RF-EMF exposure (Ahlbom et al., 2008; Bolte and Eikelboom, 2012; Frei et al., 2009b, 2010; Neubauer et al., 2007; Röösli et al., 2010). In a personal measurement, study volunteers carry the exposimeter, fill in an activity diary and ideally geocodes are recorded by GPS during the study period. The advantage of such personal measurement studies is that direct estimation of the exposure distribution in the population is obtained taking into account their behavior. However, such measurements are demanding for volunteers and bias in the selection of volunteers is of concern. They would be very costly for large collectives. Furthermore, data quality cannot be controlled and exposure recording may be manipulated by putting the devices deliberately close or far from known RF-EMF sources. Measurements are also influenced by the body of the person wearing the measurement devices that lead to underestimation of actual exposure (Blas et al., 2007; Bolte et al., 2011; Knafl et al., 2008; Neubauer et al., 2010; Radon et al., 2006). Another limitation is the lack of differentiation between exposure from one's own mobile phones use and other people's mobile phone use. Measurements taken during one's own mobile phone uses are not expected to represent the true exposure of the person (Inyang et al., 2008).

To overcome these limitations, microenvironmental measurement studies have been proposed (Röösli et al., 2010). In this case a portable radiofrequency meter is carried by a trained study assistant in different microenvironments such as residential areas, downtown areas, trains and railway stations or shopping centers and data are collected with a high sampling rate (Urbinello et al., 2014a, 2014b, 2014c). Such a survey considers microenvironments as a unit of functional observation. Hence, it allows the collection of numerous spatially distributed measurements within a short time frame. Most importantly, adherence to the measurement protocol can be controlled and the data are collected exactly where people spend most of their time. The study assistant can conduct the measurement in a way that avoids body shielding and his own mobile phone can be switched off in order to focus on environmental RF-EMF exposure from other people's phones.

To evaluate the suitability of microenvironmental measurement surveys with portable exposimeters (PEM) for monitoring of RF-EMF levels in Switzerland, a protocol for repeated measurements in various microenvironments has been developed. The aim of this study was to evaluate the repeatability and spatiotemporal variability of such measurements with respect to RF-EMF monitoring and to describe the exposure situations in these publicly accessible microenvironments.

2. Methods and materials

2.1. Site selection and description of microenvironments

We included 20 municipalities that represented the nine community types according to the Federal Office for Spatial Development (ARE) community typology (http://www.geo.admin.ch/internet/geoportal/en/home/vis.html): major centers (3), secondary centers of big centers (3), medium sized centers (2), small centers (2), belt of major centers (2), the belt of medium sized centers (2), peri-urban rural communities (2), agricultural communities (2), and tourist communities (2). From each of the 20 selected municipalities, 2–4 different microenvironments were selected for measurements (Supplementary material: Table S1). A total of 51 different microenvironments were selected to give a good representation of the entire country (5 city centers, 15 centers of rural areas, 5 central residential areas, 5 non-central residential areas, 15 rural residential areas, and 6 industrial areas). City center and central residential area refer to the areas in cities with higher buildings (4–5 floors) and few road traffic as well as numerous people on the sidewalks. Non-central residential areas are outside the city center of cities with building heights of on average 2–3 floors and relatively larger proportions of green spaces compared to central residential areas and city center. The selected rural centers have a typical building height of 2–3 floors. Industrial areas refer to zones in cities and rural areas where industries are located. In addition to the outdoor areas, EMF measurements in public transport (bus, tram and train) during the journey of the study assistant to and from the measurement areas have been considered.