Environment International 114 (2018) 297–306

Contents lists available at ScienceDirect

Environment International

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

Comparison of radiofrequency electromagnetic field exposure levels in different everyday microenvironments in an international context

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ARTICLE INFO

Handling editor: Marti Nadal

Keywords:
Radio-frequency electromagnetic fields (RF-EMF)
Microenvironment
Uplink
Downlink
Exposure assessment
Mobile phone handset
Mobile phone base station

ABSTRACT

Background: The aim of this study was to quantify RF-EMF exposure applying a tested protocol of RF-EMF exposure measurements using portable devices with a high sampling rate in different microenvironments of Switzerland, Ethiopia, Nepal, South Africa, Australia and the United States of America.
Method: We used portable measurement devices for assessing RF-EMF exposure in 94 outdoor microenvironments and 18 public transport vehicles. The measurements were taken either by walking with a backpack with the devices at the height of the head and a distance of 20–30 cm from the body, or driving a car with the devices mounted on its roof, which was 170–180 cm above the ground. The measurements were taken for about 30 min while walking and about 15–20 min while driving in each microenvironment, with a sampling rate of once every 4 s (ExpoM-RF) and 5 s (EME Spy 201).
Results: Mean total RF-EMF exposure in various outdoor microenvironments varied between 0.23 V/m (non-central residential area in Switzerland) and 1.85 V/m (university area in Australia), and across modes of public transport between 0.32 V/m (bus in rural area in Switzerland) and 0.86 V/m (Auto rickshaw in urban area in Nepal). For most outdoor areas the major exposure contribution was from mobile phone base stations. Otherwise broadcasting was dominant. Uplink from mobile phone handsets was generally very small, except in Swiss trains and some Swiss buses.
Conclusions: This study demonstrates high RF-EMF variability between the 94 selected microenvironments from all over the world. Exposure levels tended to increase with increasing urbanity. In most microenvironments downlink from mobile phone base stations is the most relevant contributor.

1. Introduction

Knowledge of the radiofrequency electromagnetic field (RF-EMF) exposure of the population is useful for risk communication, assessment and management (Dürrenberger et al., 2014). However, little is known about differences in RF-EMF exposure of the general public in various microenvironments in different parts of the world. Recent studies have quantified RF-EMF levels in different microenvironments in Europe by collecting data during walking (Bhatt et al., 2016b; Bolte and Eikelboom, 2012; Joseph et al., 2010; Knafl et al., 2008; Sagar et al., 2016; Thuróczy et al., 2008; Urbinello et al., 2014a, 2014b; Urbinello and Röösli, 2013), by driving and using devices mounted on a car (Aerts

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https://doi.org/10.1016/j.envint.2018.02.036
Received 19 August 2017; Received in revised form 8 February 2018; Accepted 22 February 2018

et al., 2016; Bolte et al., 2016; Estenberg and Augustsson, 2014) or on a bicycle (Beekhuizen et al., 2013; Gonzalez-Rubio et al., 2016). Such microenvironmental measurements have several advantages. First, all sources can be measured, including wireless local area network (WLAN) hotspots and uplink from other people's mobile phones, which is not possible for simulation studies as data on these sources are not available for large scale modeling (Beekhuizen et al., 2015; Bürgi et al., 2010). Second, collecting data by a qualified technician enables one to adhere strictly to a measurement protocol and control data quality. This may not be the case in volunteer studies, where people may manipulate measurements by putting the measurement instrument close to sources or provide imprecise activity information during the data collection measurements (Bolte and Eikelboom, 2012; Frei et al., 2010). Further, measured uplink fields can be attributed to other people's mobile phones whereas this may not be possible in volunteer studies where the uplink is a mixture of emissions from volunteers' own and other people's mobile phones. Third, larger geographical areas can be covered than with spot measurements (Joseph et al., 2010; Urbinello et al., 2014a, 2014b) while still producing high reproducibility of measurements within the same microenvironment (Beekhuizen et al., 2013; Sagar et al., 2016). Nevertheless, propagation modeling may be able to capture larger areas in a more efficient manner if accurate data of all transmitters and building data are available (Aerts et al., 2013; Beekhuizen et al., 2015). Other challenges for measurements with portable devices are the sensitivity range, out-of- band response and body shielding, if carried directly on the body (Aminzadeh et al., 2018; Bolte, 2016).

Previous microenvironmental measurement studies used slightly different variants of measurement approaches and different kinds of measurement devices, which substantially hamper comparability (Sagar et al., 2017). For instance, some exposimeters with logarithmic detectors used in earlier studies were demonstrated to overestimate signals with bursts, such as uplink signals from mobile phones and WiFi appliances (Bolte, 2016). Also different strategies have been used to minimize body shielding which occurs if the body blocks the transmission between the source and the measurement device (Bolte, 2016). Previous measurements have been done mainly in Europe except for a few studies in Australia (Bhatt et al., 2016b, 2016a). Thus, the rest of the world remains basically untouched and information on the population exposures is missing. A comparative RF-EMF measurement using a standard protocol across several countries across the globe would be highly informative and enhance our knowledge of the population exposure on a global scale. Hence this study continues the effort of Sagar et al., 2016, where a measurement procedure was developed for Switzerland to monitor RF-EMF exposure in publicly-accessible microenvironments, with the aim to quantify the exposure levels in various microenvironments in Switzerland, Ethiopia, Nepal, South Africa, Australia and the United States of America.

2. Measurements and methods

2.1. Microenvironments selection

Table S1 (Supplementary material: Table S1) provides an overview of the selected microenvironments with a schedule of their measurements across all six countries. We selected 94 microenvironments from six countries across the globe following the tested protocol in Switzerland (Sagar et al., 2016). Our selected microenvironments represent urban and rural areas across the six countries and were selected based on available resources and time to measure the exposure. We focused on microenvironments where people spend part of their time. We included urban areas with high population density as previous studies found the highest RF-EMF exposure in such areas (Bhatt et al., 2016a, 2016b; Bolte et al., 2016; Bolte and Eikelboom, 2012; Estenberg and Augustsson, 2014; Frei et al., 2009; Joseph et al., 2010; Sagar et al., 2016; Urbinello et al., 2014a, 2014b, 2014c). Within each country, the set of matching microenvironments was chosen to provide greatest comparability across countries and included city centers, central residential, non-central residential, rural centers, rural residential, industrial, tourist and university areas (Bhatt et al., 2016a, 2016b; Joseph et al., 2010; Röösli et al., 2010; Sagar et al., 2016; Urbinello et al., 2014a, 2014b). The 94 selected microenvironments comprised 15 microenvironments from Switzerland (Europe), 18 from Ethiopia (Africa), 12 from Nepal (Asia), 17 from South Africa (Africa), 24 from Australia (Australia), and 8 from the United States of America (North America). In addition to these 94 microenvironments, 18 measurements were conducted in public transportation (train, tram, bus) including taxi and auto rickshaw during the journey of the study assistant to and from the measurement areas on the day of measurement.

2.2. Measuring devices

The RF-EMF exposure measurements in all the selected international microenvironments were measured using three different kinds of portable RF meter; the “ExpoM-RF v1”, “ExpoM-RF v3” and “EME Spy 201”. The two versions of ExpoM-RF (version 1: Expom and version 3: ExpoM-RF) were developed by Fields At Work; a spin-off company in Zurich, Switzerland (http://www.fieldsatwork.ch), and the EME Spy 201 was developed by Microwave Vision Group, France (http://www.mvg-world.com/en). The frequency bands of the ExpoM-RF cover the frequencies of most public RF-EMF emitting devices currently used in Switzerland, Ethiopia, Nepal, South Africa and Australia while the frequency bands of the EME Spy 201 cover the frequencies of most public RF-EMF emitting devices currently used in the United States of America (https://www.worldtimezone.com/gsm.html) (Supplementary material: Table S2). The upper limit of the ExpoM-RF dynamic range is 5 V/m (66 mW/m^2) for all frequency bands, and the lower limit of the dynamic range varies for different frequency bands; between 0.003 and 0.05 V/m (0.024–6.6 μW/m^2). The upper detection limit of the EME Spy 201 is 6 V/m (96 mW/m^2) and the lower detection limit is 0.005 V/m (0.066 μW/m^2), except for FM, TV-VHF and WiFi 5G, where it was 0.015 V/m (0.60 μW/m^2). Although both portable devices record values below the lower detection limit, we censored the values below half of the lower detection limit by replacing it with half of the lower detection limit. However, we did not find any value above 5 V/m; all the measured maximum values were below the upper detection limit of 5 V/m.

2.3. Measurement procedure

The RF-EMF exposure measurements were conducted either by walking (the pedestrian way) in Switzerland and Nepal or driving (outside from the driveway) a car with the device mounted on its roof in United States of America or a mixture of walking and driving in Ethiopia, South Africa, and Australia (Supplementary material: Table S1). Measurements by walking were conducted using a backpack with the devices at the height of the head (160–170 cm) and a distance of 20–30 cm from the body to ensure minimum shielding, and measurements by driving a car were conducted with the devices mounted on its roof, which was 170–180 cm above the ground. The measurements in public transportation including taxi and auto rickshaw were conducted with either carrying the backpack by the study assistant or keeping it vertical on the seat of the public transportation including taxi and auto rickshaw. Personal mobile phones were switched off while taking the measurements, and a mobile phone with a time stamp app was used in flight mode to record the start and end times of each measurement while walking or driving.

Each of the selected 94 microenvironments was measured twice between 10 March 2015 and 14 April 2017 (details see Supplementary material: Table S1). The RF-EMF exposure measurements using the ExpoM-RF were taken with a sampling rate of once every 4 s, and the EME Spy 201 with a sampling rate of once every 5 s. All measurements were taken during daylight between 9 am and 6 pm in the respective