Environment International 118 (2018) 60–69

Contents lists available at ScienceDirect

Environment International

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

Children's exposure assessment of radiofrequency fields: Comparison between spot and personal measurements

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ARTICLE INFO

Handling Editor: Olga-Ioanna Kalantzi

Keywords:
Exposure assessment
Electromagnetic fields
Radiofrequencies
Children

ABSTRACT

Introduction: Radiofrequency (RF) fields are widely used and, while it is still unknown whether children are more vulnerable to this type of exposure, it is essential to explore their level of exposure in order to conduct adequate epidemiological studies. Personal measurements provide individualized information, but they are costly in terms of time and resources, especially in large epidemiological studies. Other approaches, such as estimation of time-weighted averages (TWAs) based on spot measurements could simplify the work.

Objectives: The aims of this study were to assess RF exposure in the Spanish INMA birth cohort by spot measurements and by personal measurements in the settings where children tend to spend most of their time, i.e., homes, schools and parks; to identify the settings and sources that contribute most to that exposure; and to explore if exposure assessment based on spot measurements is a valid proxy for personal exposure.

Methods: When children were 8 years old, spot measurements were conducted in the principal settings of 104 participants: homes (104), schools and their playgrounds (26) and parks (79). At the same time, personal measurements were taken for a subsample of 50 children during 3 days. Exposure assessment based on personal and on spot measurements were compared both in terms of mean exposures and in exposure-dependent categories by means of Bland-Altman plots, Cohen's kappa and McNemar test.

Results: Median exposure levels ranged from 29.73 (in children's bedrooms) to 200.10 μW/m^2 (in school playgrounds) for spot measurements and were higher outdoors than indoors. Median personal exposure was 52.13 μW/m^2 and median levels of assessments based on spot measurements ranged from 25.46 to 123.21 μW/m^2. Based on spot measurements, the sources that contributed most to the exposure were FM radio, mobile phone downlink and Digital Video Broadcasting-Terrestrial, while indoor and personal sources contributed very little (altogether < 20%). Similar distribution was observed with personal measurements.

There was a bias proportional to power density between personal measurements and estimates based on spot measurements, with the latter providing higher exposure estimates. Nevertheless, there were no systematic differences between those methodologies when classifying subjects into exposure categories. Personal measurements of total RF exposure showed low to moderate agreement with home and bedroom spot measurements

Abbreviations: RF, radiofrequency; TWA, time-weighted averages; INMA, environment and childhood (from INfancia y Medio Ambiente) cohort; DVB-T, Digital Video Broadcasting-Terrestrial; LOQ, limit of quantification; DECT, Digital Enhanced Cordless Telecommunications; Uplink, mobile phone uplink; Downlink, mobile phone downlink

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https://doi.org/10.1016/j.envint.2018.05.028
Received 9 November 2017; Received in revised form 6 May 2018; Accepted 13 May 2018
0160-4120/ © 2018 Published by Elsevier Ltd.

and agreed better, though moderately, with TWA based on spot measurements in the main settings where children spend time (homes, schools and parks; Kappa = 0.46).
Conclusions: Exposure assessment based on spot measurements could be a feasible proxy to rank personal RF exposure in children population, providing that all relevant locations are being measured.

1. Introduction

Radiofrequency (RF) fields cover the frequency range between 10 MHz and 300 GHz and are mainly used for wireless communication purposes (World Health Organization, 2016). Sources of this type of electromagnetic field are growing and hence, there is a need for research into exposure assessment to guide the design of high quality epidemiological studies. In addition, further research on the characteristics of RF exposure, such as, assessment of exposure levels from emerging sources, quantification of personal exposure levels, and prospective studies of children and adolescents are considered high priority research needs by the World Health Organization (2010).

Whether children are more vulnerable than adults to RF exposure is still being discussed (Foster and Chou, 2014; IEGMP (Independent Expert Group on Mobile Phones), 2000; Van Rongen et al., 2004) but it is expected that present-day children and adolescents will have longer lifetime exposure than present-day adults. In addition, children's exposure profile, determinants of exposure and contribution of sources may vary from those of adults'.

To date, many epidemiological studies assessing health effects of RF exposure have been focused on specific sources, such as use of mobile or cordless phones (Abramson et al., 2009; Aydin et al., 2011b; Cardis, 2010; Divan et al., 2008; Redmayne et al., 2013; Sadetzki et al., 2014; Schüz et al., 2011; Thomas et al., 2010) (most of them considering self-reported use), and on distance to some far-field sources (mobile phone base stations, television and radio antennas, whose radiation is contributing to people's exposure in the far field of the source) (Dode et al., 2011; Wolf and Wolf, 2004). These methods to assess exposure have limitations. Specifically, self-reporting of phone use has been proven to over- or under-estimate exposure sufficiently that it can lead to misclassification (Aydin et al., 2011a; Roser et al., 2015; Schüz et al., 2011) and distance per se to far-field sources has been considered an inadequate surrogate for exposure assessment (Gonzalez-Rubio et al., 2016), showing moderate (Beekhuizen et al., 2015) or low (Neitzke et al., 2007) association with exposure from mobile phone base stations and also a very low correlation with personal measurements of total RF exposure (Frei et al., 2010). Recently, efforts have been made to achieve more comprehensive exposure assessment. Many authors have tried to assess exposure by performing measurements (spot or personal) (Calvente et al., 2015; Roser et al., 2017) or by using simulations to predict such exposure (Beekhuizen et al., 2014; Bürgi et al., 2008). Nevertheless, few studies have reported data on RF exposure on children or adolescents, combining exposure from near- and far-field sources (Roser et al., 2015). Further, there is still no accepted standardized method for comprehensively assessing realistic exposure to RF fields of general public for epidemiological purposes. Personal measurements provide individualized information and consider temporal and spatial variations, but require substantially greater effort in terms of time and resources, especially in large epidemiological studies. Assessing exposure based on spot measurements may be an alternative and a proxy for personal exposure assessment. Besides, while personal measurements may be more prone to random variability or to variability introduced by specific activities, spot measurements may be better replicated and thus they could better reflect longer-term exposure at the specific sites.

Although personal measurements have been found to be moderately correlated with simulated exposure (Frei et al., 2010; Martens et al., 2016, 2015), to our knowledge, there is a lack of studies assessing agreement between personal measurements and exposure assessment based on spot measurements in the main settings of the participants. Filling this gap in the literature could help to establish whether spot measurements can be used as a proxy for personal exposure levels, which is important, as this approach would simplify research and make it more feasible to cover larger populations.

The aims of this study were to assess RF exposure in the INMA-Gipuzkoa (*Infancia y Medio Ambiente*-Environment and childhood) birth cohort (www.proyectoinma.com) (Guxens et al., 2012), by spot measurements and personal measurements in the settings where children tend to spend most of their time, i.e., homes, schools and parks; to identify the settings and sources that contribute most to that exposure; and to explore if exposure assessment based on spot measurements is a valid proxy for personal exposure.

2. Material and methods

2.1. Study population

This study was embedded in the INMA-Gipuzkoa birth cohort which is located in the Basque Country and is part of a Spanish multicenter study (Guxens et al., 2012).

The recruitment of mother-child pairs took place during the first antenatal visit (10–13 weeks of gestation) to the physician in the public referral hospital (Zumarraga hospital) between April 2006 and January 2008.

In total, 638 out of 993 mother-child pairs invited to participate met the inclusion criteria and agreed to be enrolled in the INMA-Gipuzkoa study. This study was conducted over the period 2014–2016, when the children reached 8 years of age, all cohort members were contacted; at that time, 397 children (62.2%) participated in the study.

2.2. Study procedure

2.2.1. Measurement devices

For measuring narrowband RF fields in the 87.5 MHz–6 GHz range, we used an ExpoM -RF 3 (hereinafter ExpoM) personal portable exposimeter (Fields at work, 2017). This device measures exposure to 16 different frequency bands according to emissions from different main sources: FM Radio; Digital Video Broadcasting-Terrestrial (DVB-T); LTE 800 uplink and downlink (LTE 800 UL and LTE 800 DL respectively, used for 4G); GSM 900 uplink and downlink (GSM 900 UL and GSM 900 DL, used for 2G); GSM 1800 uplink and downlink (GSM 1800 UL and GSM 1800 DL, used for 2G/4G); Digital Enhanced Cordless Telecommunications (DECT); UMTS uplink and downlink (UMTS UL and UMTS DL, used for 3G); ISM 2.4 GHz (used for WiFi); LTE 2600 uplink and downlink (LTE 2600 UL and LTE 2600 DL, used for 4G); WiMax 3.5 GHz (used for wireless internet connection mainly in rural areas); and ISM 5.8 GHz (used for WiFi). Measurement ranges are displayed in Supplementary Table 1. This meter uses a three-axis isotropic antenna. The ExpoM was calibrated by the manufacturers prior to the measurement campaign, and every 6 months during the measurement campaign, to ensure good working conditions.

2.2.2. Measurement procedure

The procedure is explained in detail in a previous publication (Gallastegi et al., 2016). In brief, we conducted measurements in the settings where children spent most of their time, which are homes, schools and parks (Basque Government, 2017). In the case of homes, measurements were taken in the living room and child's bedroom in

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