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Spatial and temporal variability of personal environmental exposure to radio frequency electromagnetic fields in children in Europe

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ABSTRACT

Background: Exposure to radiofrequency electromagnetic fields (RF-EMF) has rapidly increased and little is known about exposure levels in children. This study describes personal RF-EMF environmental exposure levels from handheld devices and fixed site transmitters in European children, the determinants of this, and the day-to-day and year-to-year repeatability of these exposure levels.
Methods: Personal environmental RF-EMF exposure (μW/m^2, power flux density) was measured in 529 children (ages 8–18 years) in Denmark, the Netherlands, Slovenia, Switzerland, and Spain using personal portable exposure meters for a period of up to three days between 2014 and 2016, and repeated in a subsample of 28 children one year later. The meters captured 16 frequency bands every 4 s and incorporated a GPS. Activity diaries and questionnaires were used to collect children's location, use of handheld devices, and presence of indoor RF-EMF sources. Six general frequency bands were defined: total, digital enhanced cordless telecommunications (DECT), television and radio antennas (broadcast), mobile phones (uplink), mobile phone base stations (downlink), and Wireless Fidelity (WiFi). We used adjusted mixed effects models with region random effects to estimate associations of handheld device use habits and indoor RF-EMF sources with personal RF-EMF exposure. Day-to-day and year-to-year repeatability of personal RF-EMF exposure were calculated through intraclass correlations (ICC).
Results: Median total personal RF-EMF exposure was 75.5 μW/m^2. Downlink was the largest contributor to total exposure (median: 27.2 μW/m^2) followed by broadcast (9.9 μW/m^2). Exposure from uplink (4.7 μW/m^2) was lower. WiFi and DECT contributed very little to exposure levels. Exposure was higher during day (94.2 μW/m^2)

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than night (23.0 μW/m^2), and slightly higher during weekends than weekdays, although varying across regions. Median exposures were highest while children were outside (157.0 μW/m^2) or traveling (171.3 μW/m^2), and much lower at home (33.0 μW/m^2) or in school (35.1 μW/m^2). Children living in urban environments had higher exposure than children in rural environments. Older children and users of mobile phones had higher uplink exposure but not total exposure, compared to younger children and those that did not use mobile phones. Day-to-day repeatability was moderate to high for most of the general frequency bands (ICCs between 0.43 and 0.85), as well as for total, broadcast, and downlink for the year-to-year repeatability (ICCs between 0.49 and 0.80) in a small subsample.

Conclusion: The largest contributors to total personal environmental RF-EMF exposure were downlink and broadcast, and these exposures showed high repeatability. Urbanicity was the most important determinant of total exposure and mobile phone use was the most important determinant of uplink exposure. It is important to continue evaluating RF-EMF exposure in children as device use habits, exposure levels, and main contributing sources may change.

1. Introduction

Over the past thirty years, new mobile communication technologies such as mobile phones and their base stations, Wireless Fidelity (WiFi) access points, among others, have been developed and continue to rapidly evolve. These mobile technologies represent the main source of exposure to radio frequency electromagnetic fields (RF-EMF) in the general population (van Deventer et al., 2011). As these sources grow more numerous every day, researchers continue to evaluate the safety of human exposure to RF-EMF, encouraging caution and emphasizing the need for further research (Ahlbom et al., 2008; Sienkiewicz et al., 2005; Röösli and Hug, 2011; Swedish Radiation Safety Authority, 2017; Baan et al., 2011). Several European studies have attempted to characterize the quantity and variability of exposure to RF-EMF in the general population and found exposures to be consistently far below recommended limits (Thomas et al., 2008a; Frei et al., 2009; Berg-Beckhoff et al., 2009; Viel et al., 2009; Bolte and Eikelboom, 2012; Vermeeren et al., 2013; Gajšek et al., 2015). Nevertheless, the public and scientific communities remain concerned about exposure to RF-EMF, particularly in children (Calvente et al., 2016; Calvente et al., 2015; Kheifets et al., 2005; Redmayne, 2016; Markov and Grigoriev, 2015). First of all, there is concern that children today are exposed to more RF-EMF than ever before and that this accumulated exposure over a lifetime could lead to adverse outcomes which have not yet been evaluated (Redmayne, 2016; Markov and Grigoriev, 2015; Rosenberg, 2013; Otto and von Mühlendahl, 2007). Secondly, there is concern that exposure to RF-EMF at a young age, while organs and the brain are rapidly developing, could lead to adverse health effects in childhood or later in life (Rice and Barone, 2000). Therefore studies characterizing RF-EMF exposure in children have been identified as high priority by the World Health Organization (van Deventer et al., 2011).

Some studies have attempted to characterize RF-EMF exposure in children from fixed site transmitters (such as mobile phone base stations or broadcast antennas) through geospatial modeling (Merzenich et al., 2008; Hauri et al., 2014; Huss et al., 2015; Schoeni et al., 2016; Guxens et al., 2016). Other studies have used exposure meters and questionnaire data to characterize children's exposure from handheld devices (such as mobile phone or tablet) and indoor sources (cordless phone base stations or WiFi) (Vermeeren et al., 2013; Thomas et al., 2009; Heinrich et al., 2011; Valič et al., 2015; Juhász et al., 2011; Roser et al., 2017). These studies have found that variations and quantity of exposure to RF-EMF can depend on many complex factors, and solely geospatial modeling or only extrapolating exposure from questionnaire data cannot accurately capture RF-EMF exposure (Röösli et al., 2010; Bolte, 2016). Personal exposure meters are considered one of the most accurate tools in assessing environmental personal exposure, allowing researchers to capture different sources of exposure, evaluate how this exposure varies over time, and validate exposure prediction models (Röösli et al., 2010; Bolte, 2016; Inyang et al., 2008; Frei et al., 2010). While methods for assessing personal RF-EMF exposure continue to evolve, so do communication technologies and children's habits for using them; therefore it is necessary to continue evaluating this exposure with the newest technologies through personal measurement studies to better understand this exposure today and in the future in children. With the ever-increasing use of mobile communication devices in the general population, and with the age of first use dropping every year, it is critical to closely evaluate RF-EMF exposure in children.

In this study, we examined levels and sources of personal environmental RF-EMF exposure, as well as its determinants, including individual characteristics, handheld device use, and presence of residential indoor RF-EMF sources, over a period of up to three days in > 500 children spanning ages 8–18 in five European countries using personal exposure meters between 2014 and 2016. We also assessed the day-to-day repeatability of these measurements in the whole sample and year-to-year repeatability in a smaller subsample whose measurements were collected twice in the same children, one year apart.

2. Methods

2.1. Study design and population

As part of three European projects to identify, describe, and assess health effects of exposure to RF-EMF in children (Vermeulen, 2016; Guxens, 2016; Röösli, 2016; Gallastegi et al., 2016), personal environmental RF-EMF exposure measurements were collected over a period of up to three days for 567 children, ages 8–18 years old, in Denmark, the Netherlands, Slovenia, Switzerland, and five regions of Spain (Gipuzkoa, Granada, Menorca, Sabadell, and Valencia). For 30 children that participated in the first round of measurements in Sabadell, Spain, measurements were repeated one year later in the same children. A standardized protocol was followed in all regions (Röösli et al., 2010).

In Denmark, the Netherlands, and Spain, children were randomly recruited for participation during follow-up visits in the local population-based prospective birth cohort. These were: the Danish National Birth Cohort (DNBC) (Olsen et al., 2001), the Amsterdam Born Children and their Development Study (ABCD) (van Eijsden et al., 2011), and the Spanish Environment and Childhood Project (INMA) (Guxens et al., 2012), respectively. In Slovenia, participants were recruited by direct invitation or public announcements (via website or advertisements in local media). In Switzerland, a little more than half of the participants were recruited from the Swiss prospective cohort study, Health Effects Related to Mobile phonE use in adolescentS (HERMES) (Roser et al., 2017; Schoeni et al., 2015a; Schoeni et al., 2015b). The rest of Switzerland's participants were recruited randomly from 10 communities of the canton Zurich within the framework of the ZuMe exposure study (Röösli et al., 2016). Informed consent was obtained from all participants' parents or guardians, or the children themselves, in accordance with each center's institutional review board or ethics committee.