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Outdoor characterization of radio frequency electromagnetic fields in a Spanish birth cohort

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ABSTRACT

There is considerable public concern in many countries about the possible adverse effects of exposure to non-ionizing radiation electromagnetic fields, especially in vulnerable populations such as children. The aim of this study was to characterize environmental exposure profiles within the frequency range 100 kHz–6 GHz in the immediate surrounds of the dwellings of 123 families from the INMA-Granada birth cohort in Southern Spain, using spot measurements. The arithmetic mean root mean-square electric field (E_{RMS}) and power density (S_{RMS}) values were, respectively, 195.79 mV/m (42.3% of data were above this mean) and 799.01 μW/m^2 (30% of values were above this mean); median values were 148.80 mV/m and 285.94 μW/m^2, respectively. Exposure levels below the quantification limit were assigned a value of 0.01 V/m. Incident field strength levels varied widely among different areas or towns/villages, demonstrating spatial variability in the distribution of exposure values related to the surface area population size and also among seasons. Although recorded values were well below International Commission for Non-Ionizing Radiation Protection reference levels, there is a particular need to characterize incident field strength levels in vulnerable populations (*e.g.*, children) because of their chronic and ever-increasing exposure. The effects of incident field strength have not been fully elucidated; however, it may be appropriate to apply the precautionary principle in order to reduce exposure in susceptible groups.

1. Introduction

The population is exposed to multiple sources of electromagnetic fields (EMF) of non-ionizing radiation (NIR) in a wide range of frequencies that go beyond radiofrequencies (RFs). This exposure has considerably increased over recent decades due to the generation of artificial electromagnetic fields from power stations, radio, radar, television, computers, mobile phones, microwave ovens, and numerous devices used in medicine and industry. These technological advances have aroused concerns about the potential health risks associated with unprecedented levels of electromagnetic fields. EMFs have been found to exert effects at experimental level and in laboratory assays (Artacho-Cordón et al., 2013), but there is less information from epidemiological studies (Hardell et al., 2011; INTERPHONE, 2010; Li et al., 2002). The recent boom in mobile communication has increased concerns about the effects of radio frequency electromagnetic fields (RF-EMF), prompting evaluation of different exposure assessment methods (Ayanda et al., 2012; Aydin et al., 2012; Beekhuizen et al., 2014; IARC, 2011; Lauer et al., 2012; Neskovic et al., 2012) and epidemiological research on their contribution to detrimental health effects. Proposed effects include brain tumors (Li et al., 2002), neurodegenerative diseases (Kesari et al., 2013), behavioral problems (Thomas et al., 2010), and psychosocial disorders (Sansone and Sansone, 2013), among other illnesses and biological alterations, although none of these effects have been definitively established (Juutilainen et al., 2011). In 2011, the International Agency for Research on Cancer (IARC) classified RF-EMFs as a possible human carcinogen (category 2B), based on the increased risk of glioma (type of malignant brain cancer) and acoustic

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neuroma (benign tumor on the nerve connecting the ear to the brain), both associated with the use of cell phones (IARC, 2011). Besides mobile communication, the increasingly widespread sources of EMFs include those from Wi-Fi, WLANs, Bluetooth, and applications related to advanced transport and data communication technologies (Foster and Moulder, 2013).

Attention has focused on the risks to children and adolescents because of their high use of mobile phones and other new technologic devices (e.g., tablets), which may be especially detrimental during critical phases of growth and development. The nervous system is considered particularly sensitive, due to its bioelectric properties (Huang et al., 2013; Saunders and Jefferys, 2007). Wiedemann and Schütz (2011) recently reviewed epidemiological and experimental studies on the effects of RF-EMF exposure in children and on their nervous system and cognitive capacity, revealing no or only scant evidence that RF-EMF exposure poses a hazard to this population. However, other authors have claimed that effects previously attributed to RF-EMFs may be the result of confounding factors (de Vocht et al., 2011; Hareuveny et al., 2011; Heinrich et al., 2010; Söderqvist et al., 2011). In fact, very few scientific data are available on the effects on human health of EMF-NIR exposure in the range of RF-EMFs. Most derive from epidemiological studies with an ecological design, comparing leukemia incidence rates among different populations and using aggregated data on exposure and disease rather than individual data (Calvente et al., 2010).

In order to improve our knowledge on the effects of RF-EMF exposure in children, it would first be useful to establish exposure profiles for different child populations. For this reason, the aim of this study was to determine total environmental levels of incident field strength within the 100 kHz to 6 GHz frequency range in the immediate surrounds of the dwellings of a birth cohort in Southern Spain.

2. Materials and methods

2.1. Study population

The recruitment and characteristics of the study population were previously reported (Calvente et al., 2014). Briefly, the study sample was drawn from the "Environment and Childhood Research Network" (INMA network), a population-based study in seven regions of Spain, which aims to explore the role of environmental pollutants in air, water, and diet during pregnancy and early childhood in relation to child growth and development. INMA is a large prospective cohort of families living in different socio-economic and environmental areas of Spain. The INMA study protocol includes medical follow-ups of the children from birth through childhood as well as epidemiological questionnaires and biological sample collections (Guxens et al., 2012). The INMA-Granada cohort was established between 2002 and 2007, enrolling eligible mother–son pairs at delivery in the San Cecilio University Hospital of Granada (province in Southern Spain). The inclusion and exclusion criteria were published elsewhere (Freire et al., 2009). When the children reached 9–10 years of age (2011–2012), all families in the cohort ($n=700$) were contacted and invited to participate in a new follow-up. A total of 300 boys were finally enrolled, and their families again completed an *ad hoc* questionnaire on their home environment, including a specific RF-EMF questionnaire. The present study included the 123 families whose outdoor RF-EMFs were measured.

2.2. Study area

The setting of the INMA-Granada study is the health district of the San Cecilio University Hospital, an area of 4000 km^2 with a total population of 512,000 inhabitants, including part of the city of Granada (236,000 inhabitants) and 50 towns and villages. Three areas of residence were differentiated: (a) urban areas, corresponding to the city of Granada and towns with more than 20,000 inhabitants, (b) semi-urban areas, towns with 10,000–20,000 inhabitants in the surrounding metropolitan area, and (c) rural areas: villages with less than 10,000 inhabitants. In the present study, children were selected from 16 towns and villages; 9.8% of households were in rural areas, 45.5% in semi-urban areas, and 44.7% in urban areas. Rural and semi-urban areas were grouped together because they shared similar features in terms of the number of emission sources and frequency ranges. Thus, the number of substations/antennas (bands) never exceeded one in the semi-urban or rural areas, whereas more than two were always observed in the urban areas. Fig. 1 depicts a map showing the localization of the 123 dwellings studied, divided between the eastern and western sectors of the province.

2.3. Equipment

Measurements were carried out using a TS/001/UB Taoma base unit (Tecnoservizi, Rome, Italy) with a TS/004/EHF isotropic electric field probe. The frequency range analyzed was from 100 kHz to 6 GHz. This equipment allows the measurement of overall electric field strength in the specified frequency range and offers the possibility of changing the unit of measurements from electric field E (V/m) to magnetic field H (A/m) or power density S (W/m^2 or mW/cm^2) values. The measurement range was from 0.2 V/m to 340 V/m, and the quantification limit was 0.2 V/m (for the sum of all frequencies), well below even the most cautious guideline levels. The probe incorporated a GPS module and was equipped with sensors for recording temperature and humidity. During the study period, the average diurnal temperature ranged between 13.1 °C and 42.2 °C and the relative humidity between 20.5% and 52.4%. The probe, connected to the base unit, was placed on an insulating tripod at a mean distance of 2 m from the child's dwelling under study at a height of 1.45 m, *i.e*., between head and chest level for the average height of the children, in accordance with IEEE recommendations (IEEE, 1987).

2.4. Band frequencies

The most important sources of RF-EMF exposure for the general public are within the frequency range measured in this study (100 kHz to 6 GHz). Table 1 shows the different frequency bands and sources used by: the Global System for Mobile Communication (GSM), including GSM 900 (925–960 MHz) and GSM 1800 (1805–1880 MHz); Digital Enhanced Cordless Telecommunications (DECT) (1880–1900 MHz); Universal Mobile Telecommunications System (UMTS) (2110–2170 MHz); and the Industrial Medical and Scientific (IMS) band 2400 (2400, 2400–2483.5 MHz).

Base station antennae were the main sources of EMF exposure that explained differences among the study areas, but other possible sources, such as wireless communication systems, cannot be ruled out. The arithmetic mean distance ± standard deviation of the investigated dwellings from mobile phone base stations emitting GSM 900 and GSM 1800 was 660.87 ± 717.48 m. This distance was less than 500 m for 50% of the dwellings; the minimum distance was 35 m and the maximum was 5000 m.

2.5. Measurements

Spot electric field measurements were performed in wideband mode between 2 pm and 4 pm, recording the average measurement at each point during 6-min periods according to national