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Radiofrequency exposure in the French general population: Band, time, location and activity variability

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ABSTRACT

Information on the exposure of individual persons to radiofrequency (RF) fields is scarce, although such data are crucial in order to develop a suitable exposure assessment method, and frame the hypothesis and design of future epidemiological studies. The main goal of this survey is to assess individual RF exposure on a population basis, while clarifying the relative contribution of different sources to the total exposure. A total of 377 randomly selected people were analyzed. Each participant was supplied with a personal exposure meter for 24-hour measurements (weekday), and kept a time–location–activity diary. Electric field strengths were recorded in 12 different RF bands every 13 s. Summary statistics were calculated with the robust regression on order statistics method. Most of the time, recorded field strengths were not detectable with the exposure meter. Total field, cordless phones, WiFi-microwave, and FM transmitters stood apart with a proportion above the detection threshold of 46.6%, 17.2%, 14.1%, and 11.0%, respectively. The total field mean value was 0.201 V/m, higher in urban areas, during daytime, among adults, and when moving. When focusing on specific channels, the highest mean exposure resulted from FM sources (0.044 V/m), followed by WiFi-microwaves (0.038 V/m), cordless phones (0.037 V/m), and mobile phones (UMTS: 0.036 V/m, UMTS: 0.037 V/m). Various factors, however, contributed to a high variability in RF exposure assessment. These population-based estimates should therefore be confirmed by further surveys to better characterize the exposure situation in different microenvironments.

1. Introduction

Despite the rapid growth of new technologies using radiofrequencies (RFs), information on the exposure of individual persons for these and older RF sources is scarce, and even less is known about the relative importance of different sources. Such data are however crucial in order to develop a suitable exposure assessment method, and frame the hypothesis and design of future epidemiological studies (WHO, 2006).

The existing RF sources are operated in different frequency bands and can be subdivided in two broad categories: external sources, such as broadcast transmitters (radio, TV), or mobile phone base stations; and internal sources, such as mobile phones, in-house bases for cordless phones (DECT), or microwave ovens. The relative contribution of these sources to exposure depends on individual home and workplace circumstances, and for a given source, the actual exposure to RF depends on a number of factors. Regarding mobile phones, characteristics of the phone (particularly the type and location of the antenna), the way the phone is handled, the distance from the base station, the frequency of handovers, and RF traffic conditions are of prime importance (Ahlbom et al., 2004). Similarly, RF fields from mobile phone base stations also exhibit a complex pattern, influenced by numerous factors such as output power of the antenna, direction of transmission, attenuation due to obstacles or walls, and scattering from buildings and trees (Neubauer et al., 2007a).

Because RFs are invisible and imperceptible, individuals cannot directly report on their exposure; if they did, their evaluation would be subjective and possibly biased due to some people's concerns about exposure. Up to now, the use of crude proxies for exposure (proximity to a base station, etc.) turned out to be inadequate, hampering the conducting of large-scale epidemiological studies (Schüz and Mann, 2000). Other studies used spot measurements that cannot be considered representative for the mean or maximal personal exposure (Bornkessel et al., 2007; Thuróczy et al., 2008). There are therefore significant challenges in assessing the exposure of individuals in the general population from RF signals, including the number and range of sources involved, and the effect of the environment on signal strengths as people move around.

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For more realistic epidemiological studies, improved individual RF exposure assessment is needed. Newly developed personal exposure meters (PEM) have become available, representing one of the best approaches to learn about the population exposure. Simple to handle, easy to carry throughout a whole day, they allow assessment of small-scale spatial and temporal variability of the exposure in daily life.

The goal of this survey, relying on such PEMs, is three-fold: to assess RF exposure on a population basis, to check its variability with time, location and activity, and to clarify the relative contribution of different sources to the total exposure.

2. Methods

2.1. Study population

To assess regional variations, this study took place in two French cities with their suburban areas and rural surroundings: Besançon (120,000 inhabitants), with a population dispersed widely in the surroundings, and a low density of RF sources; Lyon (1,200,000 inhabitants), second largest urban area in France with a high population density and numerous RF sources.

We carried out a stratified sampling, dividing the study population into urban, periurban, and rural sub-groups, according to the place of residence. French strict privacy protection laws impede any access to population census lists. In the Besançon region, we therefore took a simple random sample from the municipality staff list (for urban, and periurban sub-groups), and the Agricultural Health Insurance plan rolls (for the rural subgroup). In the Lyon region, we sampled from the University hospital staff list (employee residences being widely dispersed in the Lyon region).

A total of 398 people were enrolled into the study between December 2005 and September 2006. To minimize the temporal variability in RF transmissions, PEMs were deployed on weekdays (weekends and holidays were avoided). The choice of the day was not systematic but depended on participants and PEMs' availability. All participants gave written informed consent.

2.2. Questionnaires

Data collection and RF monitoring were overseen by four trained interviewers. On acceptance of participation, an appointment was made for a visit. Questionnaires were presented along with instructions. Data on individual, house, and workplace characteristics, as well as activities that might influence RF exposure were gathered at the beginning of the study. All participants kept a time–location–activity diary, in which they noted their location and activities every 15 min for a period of 24 h.

2.3. Exposure assessment

To estimate the dose, time pattern, and frequencies of exposure from all key sources for each individual, we used a commercial PEM, the EME SPY 120 (Satimo, Brest, France). It has three orthogonal sensors in order to provide an isotropic response, and records the electric field strength present in 12 different bands at regular intervals, with a 0.05 V/m lower detection threshold and a 5.01 V/m upper recording threshold (Table 1). WiFi networks and microwave ovens both operate in the 2.4 GHz spectrum, hampering any specific exposure assessment based solely on the PEM, although they can be separated with the time–location–activity diary. The total field was calculated as the quadratic sum of the fields measured for every single band.

Because of its limited memory capacity, each PEM was configured for a 13-second measurement period with a data collection period of 24 h, potentially yielding 6643 data points. The participants were supplied with the PEM and a bag than could be used either around the waist or over the shoulder. In the course of the measurement day, they were asked to perform their routine tasks while wearing the PEM. At night, they were asked to place the PEM next to their bed.

Table 1
Personal exposure meter frequency bands (EME SPY 120, Satimo, France).

Band name	Active sources	Range MHz
FM	VHF broadcast radio	88–108
TV 3	Digital audio broadcasting	174–223
Tetrapol	Terrestrial trunked radio	380–400
TV 4&5	UHF broadcast television	470–830
GSM[a] Tx[b]	GSM mobile phones (900 MHz)	880–915
GSM Rx[c]	GSM base stations (900 MHz)	925–960
DCS[d] Tx	DCS mobile phones (1800 MHz)	1710–1785
DCS Rx	DCS base stations (1800 MHz)	1805–1880
DECT[e]	Digital enhanced cordless telephony	1880–1900
UMTS[f] Tx	3G mobile phones	1920–1980
UMTS Rx	3G base stations	2110–2170
WiFi	Wireless networks and microwave ovens	2400–2500

[a] Global System for Mobile Communications.
[b] Transmitted radio signal from the point of view of a mobile phone.
[c] Received radio signal from the point of view of a mobile phone.
[d] Digital Communication System.
[e] Digital Enhanced Cordless Telephone.
[f] Universal Mobile Telecommunication System.

Exposure of a person depends upon time (different exposure is expected during daytime while people are working and, e.g., making phone calls compared to night time while people sleep), geographical zone (base stations are more numerous in cities), age (different mobile phone uses between youths and adults), activity (movement, standstill, sleeping, driving, etc.), and location (whether a person is indoors in a building, in a vehicle, or outdoors). Combining PEM measurements with information from questionnaires and time–location–activity diaries kept by the participants gave the opportunity to clarify the relative contributions of personal characteristics (place of residence, age category), behavioral patterns (type of activity, use of a microwave oven), and microenvironments (home, workplace, transportation). We define "day" as the period from 6 am to 10 pm, and "night" as the period after 10 pm and before 6 am.

A calibration control was conducted at the end of the study, revealing substantial variability between PEMs, as well as systematic underestimation in some frequency bands (due to a different calibration method). A series of corrections were derived and applied in five frequency bands (1.63, 1.51, 1.07, 1.69, and 1.46, for FM, TV 3, Tetrapol, UMTS uplink, and UMTS downlink, respectively). Lower detection and upper recording thresholds were modified accordingly.

2.4. Statistical analysis

One limitation of the EME SPY is its lower detection limit of 0.05 V/m generating large proportions of measurements with nondetects. The EME SPY software set each value below the detection limit to the value of the detection limit. However, such simple substitution produces over-estimates of summary statistics. An adequate treatment of these left-censored data is thus required for meaningful summary statistics. Following Röösli et al. (2008) we used a robust semiparametric method developed by Helsel and Cohn (1988) generally referred to as a regression on order statistics (ROS). It is a probability plotting and regression procedure that is considered as one of the most reliable procedures for developing summary statistics of multiple censored data (Shumway et al., 2002).

We assumed a log-normal distribution based on the experience that many environmental data are quasi log-normally distributed. Thus, robust ROS performs a log-normal transformation to input data (field strength in this study) prior to computation, and fits a linear regression of the logarithms of the data versus their normal quantiles (or "order statistics") using data above the detection limit. The obtained regression parameters are used to predict values for each censored observation. The

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predicted values are back-transformed (exponentiated) and combined with detected observations to compute summary statistics as if no censoring had occurred. These modeled censored observations are only used corporately, along with the uncensored observations, to model the distribution of the sample population. Individually, they are not considered the values that would have existed in the absence of censoring (Lee and Helsel, 2005). We required a minimum proportion of measurements (1 per 1000) above the lower detection limit to perform robust ROS calculations, resulting in the exclusion of TV3 band.

To test for differences between two or more groups of data, we used the non parametric Peto–Peto test for left-censored data. This approach is more likely to detect true differences when data come from a lognormal distribution, and is sensitive to differences in the higher values of left-censored data sets. The Peto–Peto test is therefore judged to be the most appropriate in environmental sciences (Lee and Helsel, 2007). All data were analyzed using R software (package NADA).

2.5. Ethics

Ethical clearance for this study was granted by the French National Commission for the Confidentiality of Computerized Data (no. 1104049).

3. Results

Although the logged data points were initially inspected for corrupt records, in-depth quality controls on the whole dataset indicated full or partial failures among the 10 PEMs used in this study. Two broke down entirely before the end of the study (due to a break in a cable, with no warning signal), and three had a partial disconnect among the cables. Reviewing the pattern of recordings over time resulted in post hoc exclusion of 21 participants, leaving 377 subjects for analyses (Table 2). The random sample consisted of 203 women and 174 men. The mean age was 35.8 years (standard deviation [sd]: 15.1). A total of 2,493,211 daily measurements were taken across all participants (Besançon: 1,221,716; Lyon: 1,271,495).

The numbers of measurements above the lower detection limit were few (Table 3). The highest proportions were observed for total field (46.6%), cordless phones (17.2%), WiFi-microwave sources (14.1%), and FM transmitters (11.0%). The lowest proportions were found for TV 3 (0.0%), UMTS uplink (0.9%), and for GSM uplink (1.8%).

Regarding peak exposures (assessed by the proportions of measurements above 1 V/m), the only sources of RF exposure were the subject's own mobile phone (GSM and DCS uplink), DECT phones, and microwave ovens (identified as such from the time–location–activity diaries) (Table 3). Mobile phone base stations, TV and FM antennas did not contribute. Small numbers of right-censored measurements (above the upper recording threshold) were found: 1399 in the GSM uplink, 577 in the DCS uplink, 147 in the DECT, and 94 in the WiFi-microwave bands.

The total field ROS mean value was 0.201 V/m (sd: 0.237) (Table 4). Total exposure was higher in urban areas, during daytime, among adults, and when moving (walking, bus, tramway, train or underground). When focusing on specific channels, the highest mean exposure resulted from FM transmitters (mean: 0.044 V/m, sd: 0.068). A second cluster consisted of cordless phone (mean: 0.037 V/m, sd: 0.106), mobile phones (UMTS uplink: mean: 0.036 V/m, sd: 0.018; UMTS downlink: mean: 0.037 V/m, sd: 0.019), and WiFi-microwave (mean: 0.038 V/m, sd: 0.069). Extracting data corresponding to microwave oven use (usually one or two periods of 15 mn in the time–location–activity diary) showed the heavy influence of such usage in the 2.4 GHz spectrum (mean: 0.084 V/m, sd: 0.372). Whatever the characteristics or patterns considered, all comparisons across categories were statistically significant (p-value $<10^{-2}$).

4. Discussion

This study is one of the first to assess personal band selective exposure in such a large dataset (12 channels, 2,493,211 measurements per channel), sampled from the general population, and informing about the most relevant exposure contributions in the everyday environment.

Table 2
Description of the population-based random sample (Besançon and Lyon, France, 2005–2006, 377 participants).

Region	Age category	Area		
		Urban	Periurban	Rural
Besançon	Youths	13	27	15
	Adults	32	66	32
Lyon	Youths	15	31	10
	Adults	35	68	33
Total	Youths	28	58	25
	Adults	67	134	65

Table 3
Radiofrequency measurement proportions from 377 randomly selected participants for different bands (Besançon and Lyon, France, 2005–2006).

Radiofrequency band	Proportion of measurements above the lower detection limit			Proportion of measurements > 1 V/m		
	Total	Besançon	Lyon	Total	Besançon	Lyon
FM	11.0%	12.7%	9.2%	0.0%	0.0%	0.1%
TV 3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Tetrapol	0.3%	0.0%	0.5%	0.0%	0.0%	0.0%
TV 4&5	2.7%	1.8%	3.6%	0.0%	0.0%	0.0%
GSM[a] Tx[b]	1.8%	1.6%	2.1%	0.3%	0.2%	0.4%
GSM Rx[c]	6.5%	4.4%	8.5%	0.0%	0.0%	0.0%
DCS[d] Tx	4.0%	1.0%	6.9%	0.1%	0.1%	0.2%
DCS Rx	4.8%	3.3%	6.3%	0.0%	0.0%	0.0%
DECT[e]	17.2%	14.4%	19.8%	0.2%	0.1%	0.2%
UMTS[f] Tx	0.9%	1.5%	0.4%	0.0%	0.0%	0.0%
UMTS Rx	3.0%	2.6%	3.5%	0.0%	0.0%	0.0%
WiFi-microwave	14.1%	21.1%	7.3%	0.1%	0.1%	0.1%
Total field	46.6%	46.1%	47.1%	0.7%	0.6%	0.9%

[a] Global System for Mobile Communications.
[b] Transmitted radio signal from the point of view of a mobile phone.
[c] Received radio signal from the point of view of a mobile phone.
[d] Digital Communication System.
[e] Digital Enhanced Cordless Telephone.
[f] Universal Mobile Telecommunication System.

4.1. Personal exposure meter

Whatever the PEM, some possible pitfalls when used in epidemiological field studies must be envisaged: influence of the direction of the probe when the PEM is not worn on the body, polarization of the incident waves, isolation, etc. (Knafl et al., 2008).

The tamper-proof EME SPY 120 represented a key tool for assessing actual time-averaged exposure from RFs. However, it proved to be relatively fragile in real life conditions, with weld failures for five PEMs, probably due to mechanical shocks. Unfortunately, electrical shortings between inside cables resulted in false readings appearing to show transiently signals above the lower detection threshold, when downloading the data. Only secondary careful statistical analyses highlighted this malfunctioning, obliging us to discard the data from 21 participants. Using a similar PEM, Berg-Beckhoff et al. (2008) had also to exclude measurements from a defective PEM. As we were among the first to use this PEM in a relatively large-scale field study, these limitations have been overcome in more recent surveys, which include periodic checking of PEM readings.

According to the manufacturer, the EME SPY 120 measures field strengths with a tolerance, ranging from 0.5 dB (−6% to +6%) (FM), to 2.5 dB (−25% to +33%) (DCS). This margin of error may appear broad in environmental epidemiology, but is considered typical in the RF field (Mann et al., 2005).

4.2. Exposure assessment

One limitation of this study is that the presence of the human body alters the patterns of wave propagation in its immediate proximity (Knafl et al., 2008). The PEM may be shaded by the body, its placement being mostly determined by what the individuals are able to accommodate without interfering with what they are doing. The participants indeed carried the meter differently with them (around the waist or over the shoulder). It has been shown that, due to reflection or shielding of the body, uncertainties can reach up to 30 dB for single point measurements (Blas et al., 2007). However, the movement of people over time and the presence of multipath propagation (involving wave contributions simultaneously incident on the body

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Table 4
RF measurement mean values for different frequency bands (V/m) according to regression order statistics method (Besançon and Lyon, France, 2005–2006, 377 participants).

	No. measurements	FM	Tetrapol	TV 4&5	GSM Tx	GSM Rx	DCS Tx	DCS Rx	DECT	UMTS Tx	UMTS Rx	WiFi MW	Total field
Total	2 493 211	0.044	0.005	0.016	0.013	0.018	0.012	0.015	0.037	0.036	0.037	0.038	0.201
Area													
Besançon	1221716	0.052	0.001	0.016	0.011	0.014	0.006	0.011	0.032	0.045	0.050	0.052	0.201
Lyon	1271495	0.036	0.008	0.016	0.016	0.022	0.018	0.020	0.041	0.020	0.034	0.020	0.202
Place of residence													
Urban	625 140	0.071	0.002	0.019	0.010	0.028	0.017	0.025	0.038	0.044	0.031	0.046	0.231
Periurban	1 272 213	0.039	0.008	0.015	0.014	0.016	0.011	0.014	0.038	0.038	0.040	0.037	0.201
Rural	595 858	0.013	0.005	0.012	0.015	0.009	0.010	0.006	0.034	0.019	0.050	0.042	0.156
Time period													
Day	1 657 991	0.044	0.004	0.014	0.017	0.018	0.013	0.017	0.037	0.030	0.036	0.036	0.204
Night	835 220	0.045	0.040	0.026	0.006	0.018	0.010	0.012	0.037	0.050	0.043	0.040	0.197
Age category													
Youths	727 878	0.039	0.001	0.015	0.017	0.019	0.014	0.014	0.035	0.040	0.033	0.028	0.188
Adults	1 765 333	0.047	0.007	0.016	0.012	0.018	0.011	0.016	0.038	0.037	0.039	0.042	0.206
Microenvironment													
Home	1 577 162	0.045	0.008	0.022	0.010	0.017	0.010	0.012	0.041	0.044	0.044	0.037	0.200
Workplace	543 868	0.047	0.005	0.014	0.014	0.017	0.014	0.021	0.030	0.025	0.040	0.043	0.205
Transportation	187699	0.044	0.005	0.012	0.030	0.027	0.024	0.024	0.025	0.027	0.033	0.040	0.215
Walk	37 706	0.062	0.007	0.012	0.020	0.035	0.022	0.035	0.032	0.030	0.028	0.042	0.233
Bicycle, motorcycle	8310	0.044	0.023	0.019	0.023	0.035	0.027	0.029	0.026	0.070	0.029	0.040	0.227
Car	120 378	0.037	0.005	0.012	0.031	0.026	0.022	0.022	0.024	0.025	0.038	0.039	0.204
Bus, tramway	14 390	0.055	0.002	0.017	0.034	0.028	0.040	0.024	0.020	0.004	0.027	0.042	0.238
Train, underground	6915	0.050	0.001	0.011	0.071	0.017	0.034	0.019	0.030	0.084	0.043	0.053	0.257
Others	184 482	0.036	0.007	0.008	0.021	0.025	0.018	0.016	0.028	0.012	0.024	0.033	0.192

from different directions) causes any error in time-averaged exposures to be much lower (Radon et al., 2006). Another limitation is that mobile phone measurements depend heavily on the way the device is used. A mobile phone may be held next to the user's head, but it might also be used with a headset, and the phone might be kept in the user's hand or in a pocket. So in some circumstances, the PEM rather indicates a field value measured close to the human body than the exposure of a person (Neubauer et al., 2007b).

For all these reasons, we have not attempted to determine the whole body specific absorption rates (SAR) from the electric fields measured. Values of SAR depend on the incident field parameters (frequency, intensity, polarization, source-object configuration), the characteristics of the exposed body (size, internal and external geometry, dielectric properties of tissues) and ground effects and reflector effects of other objects in the field near the exposed body. The frequency of maximal absorption (the resonance frequency) is in the FM band.

4.3. Exposure metrics

In the absence of a known biological mechanism below the thermal threshold, the mean exposure value, corresponding to a cumulative dose–response model, is the summary statistic to be preferred. In this respect, ROS method is the method of choice for estimating RF band specific mean values (Röösli et al., 2008). The strength of the ROS method is its resistance against any error due to the distribution of the data. However, the large proportion of censored values observed in our dataset (except for the total field) is a challenge for the data analysis. The statistics derived from ROS models were therefore very tenuous and should be considered with caution. On the other hand, the huge number of measurements entailed a very high statistical power, making any difference between ROS estimates statistically significant.

Two mechanisms yielded underestimates: the aforementioned body shielding effect, and right censoring (although limited) for four RF bands. But the errors introduced by inappropriate handling of censored PEM data may appear relatively small compared to the measurement uncertainty of the PEM itself (Röösli et al., 2008). A further underestimation is specific to the microwave ovens, in relation to a different time scale between their genuine use (in practice, less than 5 min), and their recorded use in the time–location–activity diary (15-minute slots).

4.4. Average field values

It is not the intention of this paper to describe realistic exposure scenarios like Joseph et al. (2008) or to go into deep detail about all comparisons for any channel. It is rather to deliver indicative results despite some limiting factors entailing variability in exposure assessment.

We found somewhat higher proportions of nondetects and lower mean values than two other pilot studies using the same PEM (Thuróczy et al., 2008; Röösli et al., 2008). This can be related to the sampling process of their populations (21 volunteers in Budapest, Hungary, and 109 participants in Basel, Switzerland, 17 of which were selected because they were living close to a fixed site transmitter), and the cruder approach used in Hungary (each value below the lower detection limit was set to this threshold, yielding overestimates).

Regarding peak exposures, individual devices (mobile phones, cordless phones and microwave ovens) dominated the exposure, while the highest mean value was found for FM transmitters, confirming some preliminary results (Thuróczy et al., 2008; Röösli et al., 2008). Among mobile phone bands, UMTS signals (uplink and downlink) had unexpectedly the highest mean values. As a matter of fact, UMTS antennas operate at low power, and a limited number of people had UMTS-enabled mobile phones at that time. These high signals could represent responses to an out-of-band frequency in the 1900 MHz range (i.e. DECT), already described by Mann et al. (2005) and reflecting the difficulty of making perfect band-pass filters.

4.5. Exposure relevant factors

Although the total field was broadly the same in both study regions, analyses per channel revealed contrasted results. The Besançon area is characterized by higher means for FM, UMTS and WiFi-microwave bands than the Lyon area. Whether these differences between areas are structural or depend on the participants' habits is still to be determined, and should be the subject of further exposure studies in various settings.

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Regarding place of residence, detailed results on residential exposure to RF fields from base stations and broadcast transmitters (in the Besançon area) have been discussed elsewhere (Viel et al., 2009). In this study, wherever a measurement was done (at home, but also at the workplace, when moving…), it was assigned to a category (rural, periurban, urban) corresponding to the place of residence and not to the exact location of the participant when the field strength was recorded. Since on average participants spent 63% of the recording day at home, the remaining 37% entails some uncertainty. Downlink GSM exposure is higher in urban areas (in agreement with Berg-Beckhoff et al., 2008), while the reverse is observed for uplink GSM exposure. This is easily explained by the much lower density of base stations in rural areas (inducing lower downlink exposures), making mobile phone calls operating at higher output power levels (inducing higher uplink exposures) (Lönn et al., 2004). However, DCS uplink and UMTS results are at variance and may be confounded by daily migrations between home and the workplace (at the time of the study, UMTS transmitters were indeed located only in urban areas). Exposure from radio and TV transmitters exhibits an increasing trend with urbanization. This trend is easily explained for the FM band, whose low power transmitters (around 100 W) serve small towns and neighbourhoods, and are therefore ubiquitous in populated areas. Conversely, because it is possible to receive public TV programs everywhere in France, we expected some similar background level, with little variation in exposure except in the vicinity of broadcast transmitters (where the vertical radiation patterns give rise to high variability in the fields measured near ground level).

The day vs. night factor broadly reflects the work/home contrast. The largest differences are observed for GSM uplink, and DCS downlink (higher values during waking hours) on the one hand, and Tetrapol, TV 4&5, and UMTS (higher values during sleeping hours) on the other. The exposure from FM, GSM downlink, DECT, WiFi-microwave bands (corresponding broadly to fixed positions) does not differ much when comparing day and night.

On the whole, adults are more exposed to RFs than youths. The main contributors are FM, Tetrapol, UMTS downlink and WiFi-microwave bands, that could partially reflect exposures at the workplace.

As expected microenvironmental RF exposure is complex. Regarding total field, outdoor levels are higher than indoor levels. Transportation gives rise to the highest exposure (in agreement with Thuróczy et al., 2008). Broadly speaking, uplink mobile phone signals are higher in car, bus, tramway, train, and underground (the high UMTS uplink value could be due to a wireless 3G connection with a laptop), while exposure from base stations was higher during walking and cycling. Higher values occurring indoor (home, workplace) are due to internal sources (DECT, WiFi-microwave), probably because downlink signals are shielded by the buildings and have to penetrate through windows and walls. WiFi signals were evenly distributed, although we would have thought that these signals were mostly present indoors. However, wireless computer networks have become commonplace in our environment, using access points to communicate with client cards, located in users' laptop computers or other portable equipment. Access points located in railway stations could explain the high value observed for train or underground. The increasing popularity of these public WiFi services may explain the exposure experienced by people using such services or by bystanders. However, public exposure is limited by the low power of the WiFi transmitters, and the very small fraction of time that the client cards or access points are actually transmitting signals (Foster, 2007).

5. Conclusion

Most of the time, recorded field strengths were not detectable with the exposure meter. The total field mean value was 0.201 V/m, higher in urban areas, during daytime, among adults, and when moving. Whether observed differences are due to true differences of exposure relevant factors, remains to be confirmed. More exposure surveys in randomly selected samples of the general population, using PEMs with a lower sensitivity limit, are therefore strongly encouraged to comprehend the exposure situation in different microenvironments, identify exposure relevant behaviors, and evaluate temporal variability of the RF exposure.

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