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Characterisation of personal exposure to environmental radiofrequency electromagnetic fields in Albacete (Spain) and assessment of risk perception

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ABSTRACT

In the last decades, exposure to radiofrequency electromagnetic fields (RF-EMF) has substantially increased as new wireless technologies have been introduced. Society has become more concerned about the possible effects of RF-EMF on human health in parallel to the increase in their exposure. The appearance of personal exposimeters opens up wide-ranging research possibilities. Despite studies having characterised personal exposure to RF-EMF, part of the population is still worried, to the extent that psychogenic diseases ("nocebo" effect) appear, and patients suffer. It could be interesting to share personal exposure results with the population to better understand and promote public health.

The main objective was to characterise personal exposure to environmental RF-EMF in Albacete (166,000 inhabitants, SE Spain), and assess the effect of sharing the results of the study on participants' risk perception.

Measurements were taken by a personal Satimo EME SPY 140 exposimeter, which was programmed every 10 s for 24 h. To measure personal exposure to RF-EMF, we worked with 75 volunteers. Their personal exposure, 14 microenvironments in the city, e.g., home, outdoors, work, etc., and possible time differences were analysed. After participating in the study, 35 participants completed a questionnaire about their RF-EMF risk perception, which was also answered by a control sample to compare the results (N = 36).

The total average exposure of 14 bands was 37.7 μW/m^2, and individual ranges fell between 0.2 μW/m^2, recorded in TV4&5, and a maximum of 264.7 μW/m^2 in DECT. For Friday, we recorded a mean of 53.9 μW/m^2 as opposed to 23.4 μW/m^2 obtained on Saturday. The recorded night-time value was 27.5 μW/m^2 versus 43.8 μW/m^2 recorded in the daytime. The mean personal exposure value also showed differences between weekdays and weekend days, with 39.7 μW/m^2 and 26.9 μW/m^2, respectively. The main source that contributed to the mean total personal exposure was enhanced cordless telecommunications (DECT) with 50.2%, followed by mobile phones with 18.4% and mobile stations with 11.0% (GSM, DCS and UMTS), while WiFi signals gave 12.5%. In the analysed microenvironments, the mean exposure of homes and workplaces was 34.3 μW/m^2 and 55.2 μW/m^2, respectively. Outdoors, the mean value was 34.2 μW/m^2 and the main sources were DECT, WiFi and mobile phone stations, depending on the place.

The risk perception analysis found that 54% of the participants perceived that RF-EMF were less dangerous than before participating in the study, while 43% reported no change in their perceptions. Only 9% of the volunteers who received information about their measurements after the study assessed the possible RF-EMF risk with a value over or equal to 4 (on a scale from 1 to 5) versus 39% of the non-participant controls.

We conclude that personal exposure to RF-EMF fell well below the limits recommended by ICNIRP and showed wide temporal and spatial variability. The main exposure sources were DECT, followed by mobile phones and WiFi. Sharing exposure results with participants lowered their risk perception.

1. Introduction

In recent years, exposure to radiofrequency electromagnetic fields (RF-EMF) has increased as new technologies have been introduced, specifically mobile phone and Internet communications (Neubauer et al., 2007). Society has become more concerned about the possible

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effects of RF-EMF on human health, and consequently on people's quality of life, in parallel to the increase in their exposure (Röösli et al., 2010b).

In this context, personal exposimeters mean more research possibilities when used in different epidemiological studies (Gonzalez-Rubio et al., 2016; Sagar et al., 2017). EME SPY models 90–200 (http://www.satimo.fr) and, to a lesser extent, ESM 140 (www.maschek.de) and ExpoM (http://www.fieldsatwork.ch), have been used in most studies.

The main advantages of personal exposimeters are that they are small-sized, easy to handle, and they offer excellent sensitivity and large data volumes (Frei et al., 2009a). In order to homogenise different studies, a protocol has existed since 2010 that offers patterns to avoid artefacts and biases (Röösli et al., 2010a). However, difficulties also exist which are: technical (effects of the human body, field strength and polarization rapidly variation over time – fading, calibrating equipment, etc.), methodological (measuring protocol) and of a data analysis-type (*non-detects*, using means, medians, etc.). These difficulties can condition research results and must be taken into account (Bolte, 2016; Bolte and Eikelboom, 2012; de Miguel-Bilbao et al., 2017; Frei et al., 2009b; Gajsek et al., 2015; Gryz et al., 2015; Knafl et al., 2008). Therefore, personal exposure assessments made with exposimeters still have some limitations (Bhatt et al., 2016) that lead to measuring uncertainties (Bolte et al., 2011; Neubauer et al., 2007).

The objectives of conducting studies with personal exposimeters were: firstly, to characterise the population's personal exposure; secondly, to measure exposure levels in different microenvironments; e.g., public transport, outdoor urban areas, other areas inside houses, etc. (Aminzadeh et al., 2016; Bhatt et al., 2016; Bolte and Eikelboom, 2012; de Miguel-Bilbao et al., 2015; Frei et al., 2009b; Gonzalez-Rubio et al., 2017; Joseph et al., 2008, 2010, 2012 Juhász et al., 2011; Markakis and Samaras, 2013; Neubauer et al., 2007; Thomas et al., 2008; Thuróczy et al., 2008; Tomitsch et al., 2010; Urbinello et al., 2014b, 2014a; Vermeeren et al., 2013; Viel et al., 2009a, 2009b, 2011). Given the limitations of these studies that affect screens, location, etc., a third kind of study has been conducted by models with which exposure has been estimated by sporadically taking measurements (Aerts et al., 2013; Aguirre et al., 2015, 2014; Beekhuizen et al., 2014, 2013; Bürgi et al., 2010, 2008; Frei et al., 2010, 2009a). Most of these studies have been conducted in Europe, but some now appear in other continents

Lack of thorough information might be the reason for a worse public health perception, especially when it comes to disorders or diseases with psychogenic components. A possible relation between a higher percentage of people affected by idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF) and the appearance of news about the disease in the press has been studied (Witthöft and Rubin, 2013). The more news on the subject that appeared in the mass media, the more related symptoms emerged. Another way that Eldridge-Thomas and Rubin (2013) dealt with the problem was to search in a database of newspaper articles in the UK, which contained key words related with IEI-EMF. The disseminated information was identified as being generally disappointing and not scientifically rigorous, but has the potential to encourage more people to attribute their symptoms to RF-EMF.

Thus misleading information about adverse RF-EMF effects may increase the likelihood of suffering symptoms, or the "nocebo" effect (Klaps et al., 2016).

The objectives of this work were to characterise personal exposure to environmental RF-EMF in Albacete (Spain), conduct a detailed study about exposure in 14 microenvironments in the city and to evaluate the effect of sharing the results of these studies on the population's risk perception.

2. Material and methods

Röösli et al. (2010a) provided a detailed protocol to take measurements of personal exposure to RF-EMF. This protocol provides basic patterns to select and instruct those who participate in the study to take measurements, and to manage and analyse data.

Fig. 1. Spatial distribution of both the participants' homes and workplaces. Icons determine the position of workplaces (measuring in these places lasted at least 4 h) and homes per gender.

2.1. Study participants

People were contacted over the project's website so they could participate as volunteers after diffusing the project to the local mass media, radio and television. Two hundred and nine volunteers from the city of Albacete (Spain) offered to participate in the study. 82 volunteers participated, of whom 56.6% were males and 43.4% were females. In all, 84.2% of the participants had WiFi and 77.6% had a cordless phone at home. The spatial distribution of the participants' homes and workplaces approximately covered the surface of the city homogeneously (Fig. 1).

2.2. Personal measurements

Four Satimo EME SPY 140 personal exposimeters were used. These devices measure 14 frequency bands, and frequencies lie between 88 MHz and 5 GHz (Table 1). This measuring equipment can record up

Table 1
Measured frequency bands and characteristics of the EME SPY 140 exposimeter. % of the measurements below the limit of detection limit or non-detects.

Band	Frequency (MHz)	Detection limit (μW/m²)	% of nondetects
FM	88–108	6.631	75.1
TV3	174–223	1.061	**98.3**
TETRA	380–390	0.265	78.5
TV4&5	470–830	0.265	**94.1**
GSM UL	880–915	0.066	86.6
GSM DL	925–960	0.066	15.1
DCS UL	1710–1785	0.066	76.1
DCS DL	1805–1880	0.066	25.7
DECT	1880–1900	0.066	18.0
UMTS UL	1920–1980	0.066	92.0
UMTS DL	2110–2170	0.066	34.8
WiFi 2G	2400–2500	0.066	50.0
Wimax	3400–3800	1.061	**98.8**
WiFi 5G	5150–5850	1.061	**98.1**

to 12,540 measurements during periods that last between 4 and 255 s. The minimum value detected by the exposimeter for each band was (in FM): 6.631 μW/m²; TETRA, TV4 & 5: 0.265 μW/m²; GSM, DCS, DECT, UMTS, WiFi 2G: 0.066 μW/m²; and (in TV3): WiMAX, WiFi 5G: 1.061 μW/m². Note that power flux density (in μW/m²) was chosen as the variable to study personal exposure. Other studies have used different units, like μW/cm², mW/m² or W/m². However, owing to typical values and the device being extremely sensitive, the use of μW/m² provides values that are easy to process, which vary mainly between 0 and 1000. Other studies have used electric fields in V/m.

The exposimeters used in our study were calibrated by the French company Antenessa/Satimo, and were configured in the same way before being handed to volunteers to ensure accurate measurements in relation to time.

An exposimeter was handed to all the participants at their homes by a research team member, who took the opportunity to explain the measuring protocol in detail and to indicate the precautions they should consider during the measuring process. Volunteers had to live a normal life avoiding the use of their cordless DECT phones and their personal mobile phones that had to carry the opposite side to the exposimeter. In case of making a call, the records were deleted. At the time they were handed out, the volunteers received and signed the measuring protocol and the personal data protection policy form. Volunteers had to complete a personal diary with information about entering and leaving each place they visited. They were also given a plastic wrist watch that was synchronised with the exposimeter and a GPS Vision Tac receiver. The GPS was complemented with the diary because signals were lost inside buildings.

The personal exposimeter was programmed to take measurements every 10 s over a 25-h period. Only 24 h was considered for the data selection and analysis because the measurements recorded in the first half hour and the last half hour during the measuring period were ruled out. When the equipment was handed out, volunteers answered a questionnaire that allowed all the data required for the study to be completed.

One of the main problems while conducting the study was that the batteries did not last long, and constantly failed due to the 10-second sampling period that lasted 25 h. The batteries supplied by the manufacturer began to fail after a few charge/discharge cycles, so we resorted to professional batteries: Eneloop Pro (2500 mAh), EBL (2800 mAh) and Ansmann (2850 mAh).

Volunteers carried the exposimeter in a plastic rucksack across their chest to make its transport more comfortable while performing their daily living activities; e.g., going to work, walking, leisure, shopping, etc., while leading a normal life. When stationary, volunteers had to leave the exposimeter near them, but far away from walls, and never on the ground or close to electronic devices. Neither the watch, nor the GPS receiver nor the rucksack interfere with the exposimeter measurements.

After measuring, researchers once again visited volunteers to collect the material and, as witnessed by volunteers, data were acquired, along with a preliminary explanation of the obtained results. Next data were filtered, processed and analysed, and an informed report of the results was sent.

2.3. Microenvironment measurements

As previously indicated, each volunteer had to make a note in the diary of the locations they had visited at all times, as well as the route they had followed through the city. This information was used to classify the 648,000 recorded measurements into microenvironments. Initially 14 microenvironments were taken: when volunteers were at home (home); when they went outside (outdoors); at their workplace (work); the place where they meet their family and friends (Family and Friends); inside their car (car); on public transport (public transport); in a restaurant, bar, café, disco, etc. (restaurants); in a sports hall (sports hall); at university (university); in schools and nurseries (school); at hospital (hospital); in shops (shopping); outside the city (outskirts) and elsewhere (other).

2.4. Calculating mean values

When the measuring process had ended, a statistical data analysis was done, and the exposimeter software (EME SPY Analysis V3.20), the R software and the SPSS package (v22) were used. Calculations were done with the electromagnetic wave intensity values, expressed as μW/m².

Before determining the mean values, data were filtered by removing those records for which errors were detected due to, for instance, coupling bands or any error values recorded by the device.

The values below the exposimeter's limit of detection for each frequency band were processed (Table 1), which was done by determining the mean values of the fitted data by a robust regression on order on statistics (ROS) method (Helsel, 2005; Röösli et al., 2008). This analysis stage was done with the NADA package of the R Software. Both the mean temporal (day of the week, daytime and night-time, and weekdays/workdays, weekend and bankholidays) and spatial (in the various microenvironments) values were determined with the data that corresponded to each case and to each volunteer. The daytime data were those recorded between 07:00:00 h and 21:59:59 h.

2.5. Assessing risk perception

In order to analyse the possible effect of volunteers' participation in the study and access to information about the exposure measurements that they had taken, after the study a series of questionnaires were completed using Google Forms, which they received by email. A random sample of non-participants from different areas in the city was formed to assess their risk perception with the same questionnaires. The participants in the study were also asked about their satisfaction for having volunteered and the impact that participation could have on their perception. Questionnaires were completed by 71 people, 35 from voluntaries group and 36 from non-participant group.

Finally, a comparative analysis was carried out of the RF-EMF exposure-related risk perception on health with the volunteers who participated in the study and with the non-participant group to assess if involving the population in such studies and sharing the results with them could change their risk perception.

3. Results

3.1. Participants and the taken measurements

Measurements were taken between 2010 and 2014 before the fourth-generation (4G) cellular telecommunication network was implemented into the city that uses LTE bands. Eighty-two volunteers participated in the study, but only 75 were valid. The other seven individuals were removed from the study due to exposimeter failures (battery failing to last; 4 cases), did not fulfil the protocol (2 cases) and did not complete the diary (1 case).

The records provided data that covered 1800 h, with 10-second interval, during which volunteers lived a normal life and freely moved around the city. In all, 648,000 records were obtained with the 14 studied frequency bands, which represented 9,072,000 data. Of these, 6,104,480 (67.4%) were non-detect values, and 2,957,020 (32.6%) were values above the exposimeter's threshold value. Table 1 provides the percentages of non-detects per frequency band. The bands related to the TV3, TV4&5, WiMAX and WiFi 5G recorded percentages of non-detects of the environment or went above 95%. The uplink (UL) bands, which correspond to mobile telecommunication systems GSM, DCS and UMTS, also recorded many non-detect values: 85.6%, 76.1% and 92.0%, respectively. Only the downlink, WiFi and DECT bands recorded percentages of non-detects below 50%. For several reasons, such as failing equipment, a measurement taken near a DECT terminal or leaving the exposimeter at home, 10,874 data were rejected (which represents only 0.12%), of which 2880 data corresponded to DECT values that saturated the equipment when the volunteer left it near a cordless phone base unit (0.03%).

3.2. Mean personal exposure and contribution of different RF-EMF sources

The mean personal exposure of the whole study period and for all the bands was 37.7 μW/m^2. Fig. 2 depicts the percentages contributed by each frequency band to total exposure. The highest percentage went to cordless phone technology DECT (51.9%), followed by mobile phone systems (uplink with 19.0%, and downlink with 11.4%), and then by WiFi (12.5%).

The mean personal exposure of cordless phones (DECT) was the highest recorded one with 264.7 (μW/m^2), followed by that produced by WiFi 2G (63.9 μW/m^2) and the Uplink band of DCS (61.5 μW/m^2). The other two uplink bands from mobile phone aerials obtained values of 24.8 μW/m^2 (GSM UL) and 10.7 μW/m^2 (UMTS UL). The Downlink bands from telecommunication bases gave mean values of 34.3 μW/m^2 (GSM DL), 15.5 μW/m^2 (DCS DL) and 8.5 μW/m^2 (UMTS DL), whereas FM radiation reached 24.5 μW/m^2.

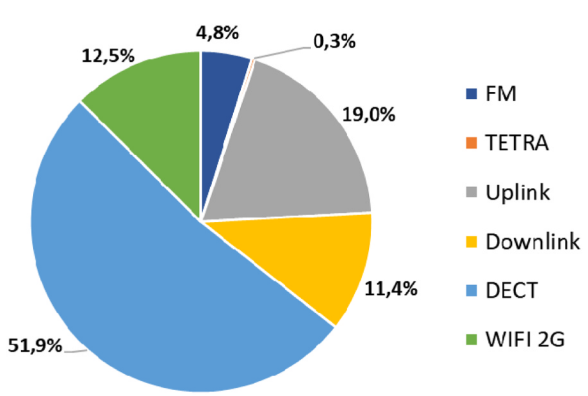

Fig. 2. Total exposure (power flux density) from the mean contributions of RF-EMF sources. Those frequency bands with a percentage of non-detects that came close to or went above 95% are not shown; mobile phone bands are grouped into Uplink and Downlink (see Table 1).

3.3. Spatial characterisation of personal exposure to RF-EMF

Table 2 provides the mean exposure values for each frequency band recorded in the studied microenvironments, as well as the 95th percentiles. Of all the bands, the recorded values due to radiation produced by cordless phones stood out in both microenvironments. The next band with a stronger effect on total exposure was wireless WiFi communication networks.

The largest number of records was taken from each volunteer's home, followed by the workplace. Both added up to 81.3% of all the study records, followed by the measurements taken in public transport, and at family and friends' homes. Except for public transport, DECT stood out as the main source of personal exposure, followed by radiation from mobile phone bases and Uplink links, whose breakdown was not included. However, in other locations like car, public transport, shops or shopping centres, the radiation that contributed most to total exposure was that from the Uplink links of mobile phones, followed by DECT and by WiFi in hospitals.

Fig. 3 represents the personal exposure frame in the main analysed microenvironment (those that reached at least 1% of all the recorded data; see Table 3), along with the percentage of each studied band's contribution. The most predominant frequency band for volunteers' home, workplaces or family and friends' homes, but also outdoors, was DECT, followed by Downlink. However, in a car, public transport, shops and other buildings, which is a wide-ranging category, this maximum contribution was made by the Uplink band. Despite a high percentage of participants (84.2%) having WLAN at home, WiFi radiation only presented a high value in hospitals.

Table 3 includes the total mean exposure values, the percentage of the measurements recorded in each microenvironment and the band that contributed the most to total exposure, along with its value.

Fig. 4 represents the mean power flux density values for each microenvironment (those that reached 1% of all the taken measurements). The microenvironment where the highest exposure value was recorded was in family and friends' homes, with a mean DECT value of 661.8 μW/m^2, followed by the workplace with a mean total exposure value of 55.2 μW/m^2. Once again, DECT was the band that contributed the most with 506.9 μW/m^2. It is noteworthy that the mean radiation outdoors was low, with a value of 34.2 μW/m^2.

To simplify the results presentation, the six mobile telecommunications bands (3 downlink and 3 uplink) were combined in all cases. Nonetheless, it is worth stressing that the mean exposure values were 14.3 μW/m^2 (UMTS DL), 20.8 μW/m^2 (DCS DL) and 29.6 μW/m^2 (GSM DL), as opposed to 22.7 μW/m^2 (UMTS UL), 56.5 μW/m^2 (DCS UL) and 29.6 μW/m^2 (GSM UL).

3.4. Temporal characterisation of personal exposure to RF-EMF

As previously pointed out, all the taken records were also classified according to temporal factors: day of the week, daytime or night-time, and weekdays (Monday to Friday) and weekend days (Saturday and Sunday). Table 4 includes the mean total personal exposure values for each studied period of time, which are shown in three blocks: for day of the week, by distinguishing between daytime and night-time, and if it was a weekday or a weekend day. Weekdays accumulated 78.5% of records, while weekend days recorded 20.1% and 1.3% during bank-holidays. Although we attempted to distribute the measurements as homogeneously as possible over weekdays, Mondays obtained the smallest value, 11.4%, and 12.0% was obtained for Thursdays. Volunteers' availability and ensuring that their usual activity was not altered conditioned this aspect to a great extent.

The mean total exposure values went from 23.4 μW/m^2 on Saturday to 54.0 μW/m^2 on Friday. The difference between daytime and night-time was 16.2 μW/m^2, and the exposure recorded for night-time was lower. In all cases, the main exposure source was DECT with values between 82.9 μW/m^2 for Saturday and 420.3 μW/m^2 for Friday.

Table 2
Mean exposure in μW/m² (M) and 95th percentile (P95) per frequency band for each microenvironment. The Family and Friends microenvironment is denoted by "F&F".

	FM		TETRA		Uplink		Downlink		DECT		WiFi	
	M	P95	M	P95	M	P95	M	P95	M	P95	M	P95
Home	26.3	98.8	2.0	4.2	21.0	0.7	14.4	59.7	247.1	802.0	80.2	89.8
Outdoors	12.2	37.6	2.4	5.4	35.0	7.8	60.2	210.3	143.2	116.0	19.0	7.2
Work	20.2	38.8	0.5	2.2	25.6	6.5	43.7	148.7	506.9	1580.0	34.2	49.8
F&F	11.8	8.3	0.5	1.8	36.5	0.7	9.3	35.4	661.8	1946.5	21.4	38.8
Car	23.5	32.1	1.6	3.6	58.3	3.7	25.0	92.7	9.6	25.0	47.7	59.2
P. Transport	1.5	0.5	0.2	0.7	86.0	29.8	24.6	112.5	2.8	10.2	9.9	2.3
Restaurants	2.3	10.2	0.6	3.8	77.9	23.3	2.5	2.6	19.8	90.8	22.5	90.8
Sports hall	2.2	7.5	0.2	0.1	25.1	11.2	51.4	238.1	11.6	35.1	12.2	3.4
University	14.0	73.1	0.1	0.0	25.2	48.5	5.1	4.6	5.3	11.6	23.8	141.8
School	1.8	10.4	0.7	1.1	57.8	4.1	18.0	81.6	15.0	15.8	3.9	12.9
Hospital	3.2	7.7	1.8	9.9	38.3	27.6	7.5	27.8	15.0	31.5	7.5	29.8
Shopping	4.2	12.3	0.3	0.5	48.0	22.3	11.1	27.2	66.9	206.0	15.9	40.8
Outskirts	3.8	12.4	0.3	0.2	7.6	5.1	7.4	8.9	7.2	8.1	35.5	5.0
Other	9.3	17.7	0.1	0.2	371.0	95.2	5.4	11.5	77.9	217.7	16.4	36.3

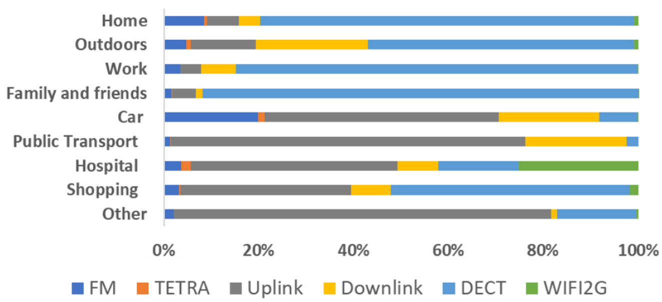

Fig. 3. Mean RF-EMF contribution to total personal exposure (power flux density) by microenvironment. Those microenvironments which did not reach 1% of all the measures are not shown (see Table 3).

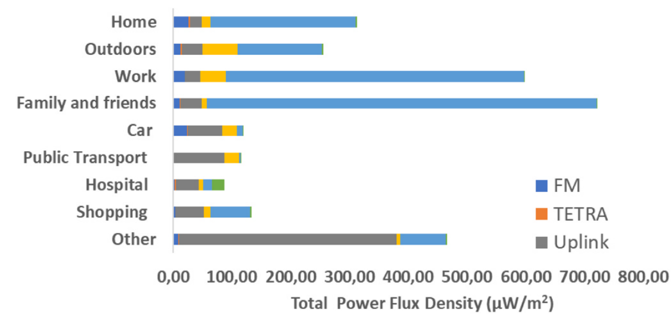

Fig. 4. Total power flux density per microenvironment. Those microenvironments which did not reach 1% of all the measures are not shown (see Table 3).

Table 3
Frequency bands with the highest recorded level for each microenvironment and the percentage of values recorded in each microenvironment. The Family and Friends microenvironment is denoted by "F&F".

	Total mean (μW/m²)	Maximum exposure frequency band	Max (μW/m²)	% measurements
Home	34.3	DECT	247.1	70.2
Outdoors	34.2	DECT	143.2	4.7
Work	55.2	DECT	506.9	11.1
F&F	61.1	DECT	661.6	3.7
Car	24.5	UpLink	58.3	1.1
P. Transport	24.7	UpLink	86.0	6.7
Restaurants	21.2	UpLink	77.9	**0.1**
Sports hall	18.5	Downlink	51.4	1.9
University	9.8	UpLink	25.2	**0.5**
School	18.0	UpLink	57.8	**0.3**
Hospital	15.3	UpLink	38.3	**0.1**
Shopping	19.2	DECT	66.9	**0.6**
Outskirts	6.8	UpLink	7.6	1.8
Other	94.6	UpLink	371.0	1.2

Table 4
Mean total exposure and maximum exposure frequency band recorded during each period of time and the percentage of values recorded during each period.

	Total mean (μW/m²)	Maximum exposure frequency band	Max (μW/m²)	% measurements
Monday	42.8	DECT	415.3	11.4
Tuesday	39.5	DECT	305.5	18.0
Wednesday	32.1	DECT	82.9	19.4
Thursday	31.8	DECT	275.4	12.0
Friday	53.9	DECT	420.3	19.0
Saturday	23.4	DECT	90.5	14.2
Sunday	35.0	DECT	351.2	6.0
Night	27.5	DECT	231.5	37.5
Day	43.8	DECT	284.4	62.5
Workday	39.6	DECT	276.1	78.5
Weekend	26.9	DECT	167.9	20.1
Bankholiday	86.0	DECT	1049.7	1.3

Table 5 offers the mean (M) values and the 95th percentiles (P95) for each frequency band and per studied period.

Fig. 5 represents the mean total exposure values for each studied period of time and the 95th percentiles (P95).

3.5. Assessing personal RF-EMF risk perceptions

The third study objective was to assess if participating as volunteers could change their RF-EMF risk perceptions. All the volunteers received a detailed report of the results of their measurements and an in-depth explanation of them. To compare the results, people who did not participate in the study were asked the same questions. The online questionnaire was answered by 35 participants at least 1 year after they participated (Fig. 6).

To assess the possible effect of participating in the study, participants' answers were compared with the people in the random sample of 36 inhabitants from the city of Albacete who did not participate in the study. Fig. 7 shows the answers to the question, where those surveyed had to indicate the degree of perceived hazardousness of RF-EMF on a scale from 1 (none) to 5 (completely). Of the group of participants in our study, 21 of 35 indicated that there was no relation between health and RF-EMF, and only three stated that this relation was real. However, among the randomly selected people who did not record measurements,

Table 5
Mean in μW/m² (M) exposure and 95th percentile (P95) per frequency band of each studied period of time.

	FM		TETRA		Uplink		Downlink		DECT		WiFi	
	M	P95	M	P95	M	P95	M	P95	M	P95	M	P95
Monday	10.3	37.6	1.2	4.0	16.7	0.9	17.7	48.0	415.3	874.0	53.4	74.0
Tuesday	8.5	30.4	3.1	3.4	24.2	0.7	23.9	81.1	305.5	958.0	86.9	127.0
Wednesday	17.5	84.0	1.5	8.6	55.2	3.7	39.4	102.8	82.9	177.0	52.6	40.1
Thursday	33.3	168.0	0.2	0.3	19.9	0.6	7.4	22.8	275.4	1040.0	49.9	74.0
Friday	41.6	166.0	0.7	2.4	46.5	1.7	9.2	32.2	420.3	1180.0	69.3	117.0
Saturday	40.0	247.0	3.0	5.1	26.5	1.0	9.8	33.2	90.5	359.0	78.2	69.6
Sunday	15.0	62.1	0.8	1.9	5.9	14.9	23.1	94.4	351.2	1800.0	28.9	23.9
Night	27.9	95.8	1.8	4.5	11.2	0.4	11.6	44.6	231.5	682.0	27.3	39.5
Day	22.5	79.4	1.5	3.1	45.0	3.7	24.1	73.8	284.4	797.0	86.0	105.0
Workday	21.0	67.1	1.5	3.4	35.9	1.5	21.2	67.4	276.1	698.0	64.7	79.4
Weekend	32.6	140.0	2.3	3.4	20.4	7.6	13.8	62.3	167.9	713.3	63.6	55.0
Bankholiday	108.5	347.3	0.1	0.4	5.2	0.3	2.1	9.5	1049.7	4880.0	22.8	32.7

nine indicated that there was no relation, as opposed to 14 who stated that the risk was real.

Two tests were used to assess the differences in participants and non-participants' answers: a Chi-square test and a Mann-Whitney *U* test. A Chi-square test concluded that the differences were statistically significant ($p < 0.01$). When taking the variable as a continuous variable, we observed that the group of participants presented a mean of 3.2 and a median of 3.0 as opposed to 2.2 and 2.0, respectively, of the group of non-participants. The Mann-Whitney *U* test concluded that the answers differed ($p < 0.01$) so the participants in the study had a lower risk perception than the non-participants.

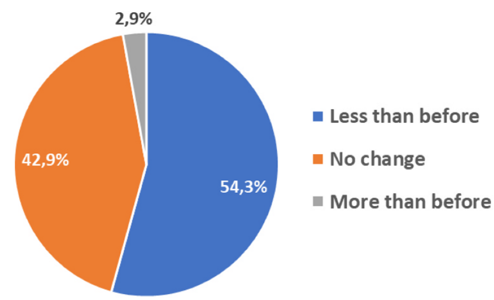

Fig. 6. Participants' answers to the question "Do you think that your participation in the study has changed your RF-EMF risk perception for health?".

4. Discussion

The protocol used sets out basic patterns to select and instruct participants in a study to take measurements, and to manage and analyse data (Röösli et al., 2010a).

Despite the problems described by Bolte (2016), this study type is a reliable tool for the personal characterisation of RF-EMF, and it provides measurements in different microenvironments and during several periods of time where measurements taken by fixed measuring devices would be complex. Viewing the exposure recorded by a volunteer during a 24-h study allows a description to be made of all the different situations and environments that have taken place and been visited on one day of participants' lives. One of the main problems with this type of studies is the effect that the body can have from carrying a single measuring device on one side (Najera Lopez et al., 2015). With several volunteers, we explored the solution of carrying two measuring devices, one on each side, but it would make living a normal life over 24-h periods impossible. We found that the measuring devices ended up on the same side of the body or on the volunteer's back, and brought close against each other, which would all interfere with recordings. Having

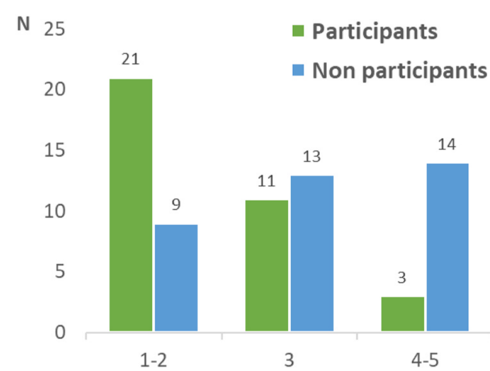

Fig. 7. Participants' and non-participants' answers to the question "Indicate on a grouped scale from 1–2 to 4–5 what degree of health hazard".

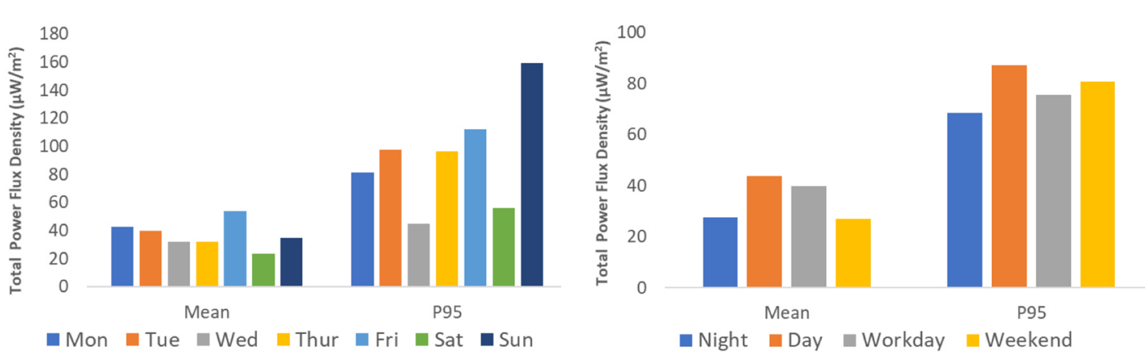

Fig. 5. Mean total power flux density and the 95th percentile (P95) per studied period of time.

exposimeters that better adjust to volunteers' clothing, or could be distributed to avoid the effect that the body could have, would be most useful (Bhatt et al., 2016).

Measurements were taken between 2010 and 2014 before the fourth-generation (4G) cellular telecommunication network was implemented into the city that uses LTE bands. Nowadays, and since then, measurements have been, and still are, taken thanks to new volunteers to run a comparative analysis in a second study phase by verifying the temporal variations caused by these new emission sources.

This study characterised personal exposure to RF-EMF of 14 frequency bands, which were both spatial and temporal, while volunteers lived normal lives during 24-h periods, and measurements were taken every 10 s. The mean recorded exposure value was 37.7 μW/m^2 (0.11 V/m), which is comparable to the values recorded in other similar studies (Sagar et al., 2017). This enabled us to check that personal exposure in different European cities is similar and below the limits set out by ICNIRP (Urbinello et al., 2014b). Given the great variability of the results, the tables are collected without homogeneity in terms of the number of significant figures and are presented with a single decimal.

The main source of radiation was cordless phones (DECT), which provided most of the exposure in the different studied microenvironments and for several periods of time, and was even the main source outdoors. It is stressed that the use of DECT phones is very widespread in shops, businesses and homes in Spain. Indeed 77% of our participants had such a device, which could partly explain this result. Bolte et al. (2012) verified that at night-time, the main exposure source was cordless phones (DECT), and these authors reported exposure values of 64 μW/m^2 compared with the 231.5 μW/m^2 recorded in Albacete. Bolte (2016) has already pointed out to the limitations of this personal exposimeters: "signals with a duty factor, such as WiFi, will not be correctly measured and exposimeters tend to overestimate the actual exposure". From this perspective the high DECT measurements reported in this paper are highly suspicious. The contribution is quite higher than in other recent publications. It is thus unclear whether DECT exposure in Spain is very different from the rest of Europe or whether this result is rather due to biased measurements.

As previously mentioned, throughout the measuring period none of the obtained values exceeded those set out by ICNIRP, set at around 50 V/m (6.6·10^6 μW/m^2), which means that our recorded values were between 1000- and 100,000-fold below them. In the Spanish Autonomous Community of Castilla-La Mancha, where the city of Albacete is found, the maximum legal exposure level is 6.1 V/m (1.0·10^5 μW/m^2), regardless of frequency band. Neither our values recorded for any frequency band nor the total contribution of the 14 bands came close to this value.

It is worth stressing that the distribution of our selected participants practically covered the whole city. However, people more concerned about this issue might have participated as it is extremely difficult to take measurements with a random population sample because volunteers need to be motivated if the study is to be properly conducted. Notwithstanding, this fact may not have necessarily conditioned our study results. One of the main problems that we encountered was finding volunteers who were really willing to carry equipment in a rucksack for 24 h and to note all the information. Each volunteer was previously trained to ensure that they would correctly follow the protocol, which considerably prolonged the whole process. Thus, data were obtained and presented to the volunteers when equipment was collected, and they were asked a series of questions to ensure that they had properly followed the protocol.

Measurements were taken with EME SPY 140 exposimeters, a personal diary, a wrist watch timer, and a GPS Vision Tac. Since many measurements were taken inside buildings, the GPS signal was often lost, so the location data might not be correct or as accurate as expected. Thus, thanks to the volunteers carrying and completing a personal diary to write down all the times they entered and left the places they visited, all the measurements could be geolocated.

One of the main challenges that we faced with the data analysis was to process those values below the threshold, known as non-detects (Röösli et al., 2008). As our results indicate, very few bands recorded less than 50% of non-detects: only the three downlink bands of mobile phones and DECT. In the first case, the recorded personal exposure values were very low, unlike DECT which contributed the most to the total exposure in many of the studied temporal and spatial situations.

Given the distribution of the frequencies of recorded data, where there were many very low-intensity values, and which were generally non-detects, the calculation of the mean value by ROS had to be always accompanied by at least a 90th or a 95th percentile (Frei et al., 2009a). This allowed us to describe the data distribution more realistically. A data analysis that does not consider non-detects, a naïve approach, by reducing the effect by adding the number of very small values to the analysis (estimations below the non-detect value), will help to reduce the effect of underestimating values in such studies (Bolte et al., 2011).

This study provides an approach to which could be an effect on participants' risk perception. The main difficulty was contacting the volunteers at least 1 year after the study, which meant that we collected very few answers: 35 of the 75 participants. Despite this limitation, this work intended to evidence the positive effect of involving the population that is most concerned about this issue in studies.

5. Conclusions

This study was conducted during the 2010–2014 period, and describes personal exposure to environmental RF-EMF in the city of Albacete (Spain) in both temporary (with a 10-second temporal resolution) and spatial (it covered 14 microenvironments) terms.

Levels of personal exposure were extremely low for all the frequencies compared to the levels set by ICNIRP and those set out in local legislation.

Involving volunteers beyond simple data collection tasks by allowing them to participate and to receive information about the results could help reduce the population's risk perception, and may help reduce the most frightened population's fears.

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Conflict of interests

There is no conflict of interests

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