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What is the radiation before 5G? A correlation study between measurements in situ and in real time and epidemiological indicators in Vallecas, Madrid

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A R T I C L E I N F O

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A B S T R A C T

Background: Exposure of the general population to electromagnetic radiation emitted by mobile phone base stations is one of the greater concerns of residents affected by the proximity of these structures due to the possible relationship between radiated levels and health indicators.
Objectives: This study aimed to find a possible relationship between some health indicators and electromagnetic radiation measurements.
Methods: A total of 268 surveys, own design, were completed by residents of a Madrid neighborhood surrounded by nine telephone antennas, and 105 measurements of electromagnetic radiation were taken with a spectrum analyzer and an isotropic antenna, in situ and in real – time, both outside and inside the houses.
Results: It was shown statistically significant p - values in headaches presence ($p = 0.010$), nightmares ($p = 0.001$), headache intensity ($p < 0.001$), dizziness frequency ($p = 0.011$), instability episodes frequency ($p = 0.026$), number of hours that one person sleeps per day ($p < 0.001$) and three of nine parameters studied from tiredness. Concerning cancer, there are 5.6% of cancer cases in the study population, a percentage 10 times higher than that of the total Spanish population. **Discussion**: People who are exposed to higher radiation values present more severe headaches, dizziness and nightmares. Moreover, they sleep fewer hours.

1. Introduction

Today, the increase in electromagnetic exposure relative to non-ionizing electromagnetic fields is evident due to the important advances that are taking place in telecommunications technologies (WHO, 2007). Non-ionizing radiation is defined as radiation that does not appear to produce alterations in the molecular structure of living tissues, but could affect the cellular functioning and physiology of the human body in terms that are still under study such as trigger oxidative stress (Renke and Chavan, 2014). With the continuous growth of telecommunication technology, the need for epidemiological scientific studies that attempt to relate exposure to radiofrequency electromagnetic fields (RF – EMFs) and the possible adverse effects that they could cause becomes evident (Wiedemann and Schütz, 2011). Although since 1998, the International Commission for the Protection of Non-ionizing Electromagnetic Radiation (ICNIRP) maintains the position of the lack of scientific evidence on the possible adverse effects resulting from exposure to RF – EMFs (Matthes et al., 1999), in 2011 The International Agency for Research on Cancer (IACR) classified the electromagnetic fields produced by base telephone stations as possible carcinogens for humans (Group 2B) (International Agency for Research on Cancer, 2018). Numerous studies focus on cellular aspects and consider that exposure to electromagnetic radiation produced by mobile phones can cause cellular process that could lead to the onset of cancer (Havas, 2017). Besides, epidemiological studies focused on other health indicators such as headaches, fatigue, loss of appetite or insomnia are a minority group, although the increase in people who suffer from it and could be attributed to electromagnetic fields is of great importance, although very few relate them to actual measurements made in the homes of the people surveyed (Belpomme et al., 2018; Belyaev et al.,

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2016; Navarro et al., 2003; Oberfeld et al., 2004).

The placement of antennas and other communication infrastructures, especially in densely populated neighborhoods, is omnipresent, that is, no one can assure that people are isolated from the effect of the radiation emitted by these stations, which causes concern about the health of those whose homes are closed to these structures, undergo evident growth (Dode et al., 2011; Khurana et al., 2010; Levitt and Lai, 2010; Wolf and Wolf, 2004). Fear of these possible adverse effects, especially from those who live closer, makes them wonder if current health protection measures against exposure to radiofrequencies used in communication systems are based on correlation studies between the exposure rate and the effects on their health conditions (Matthes et al., 1999). Mobile device users will reach 5400 million in 2020, 70% of the world population estimated for that year, according to the Visual Networking Index - Forecast of global mobile data traffic since it is expected to increases almost seven times between 2017 and 2022. According to 2020 data, the world mobile population amounted to 4.8 billion, which represents 45.04% of the world population (Ash Turner, 2020). 5G devices and connections will be more than 10% of global mobile devices and connections in 2023. The number of devices will grow, growing from 8.8 billion in 2018 to 13.1 billion by 2023, with 1.4 million 5G devices. WiFi access points are expected to multiply by four from 2018 to 2023, giving a total of 628 million public WiFi points. The figure is higher than international projections on access to some public services such as electricity (3.5 billion) and potable water (3.5 billion) or other consumer goods such as automobiles (2.8 billion), with almost 8.6 billion antennas (Cisco, 2020). Therefore, the number of large and small installations will continue to increase with the arrival of the new 5G generations, in addition to other WiFi communication systems, Wimax, etc.

Mobile phone antennas in the 100 kHz to 300 GHz band have been regulated by different international indications (Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2002; European Committee for Electrotechnical Standardization, 2008; IEEE, 2006; Kwok and Means, 2001) where the procedures for evaluating the radiation index in the population have also been defined, according to the CENELEC procedure (Cisco, 2020).

The International Commission for the Protection against Non-Ionizing Radiation (ICNRP) establishes the limits of radiation intensity for different frequencies. This non-governmental organization, formally recognized by the World Health Organization (WHO), evaluates the results of scientific studies carried out around the world and develops guidelines in which it establishes recommended exposure limits (WHO, 2007). The limits on exposure to electromagnetic radiation depend on each country, countries like Spain, Germany and France allow exposure limits of 450 $\mu W/cm^2$ for a frequency of 900 MHz and 900 $\mu W/cm^2$ at frequencies of 1800 MHz. Others such as Belgium (112.5 $\mu W/cm^2$ for 900 MHz, 225 $\mu W/cm^2$ for 1800 MHz), Austria (Salzburg, 0.1 μW/cm2 for 900 MHz and 1800 MHz) or Switzerland (4.2 μW/cm2 for 900 MHz, 10 μW/cm2 for 1800 MHz) are more restrictive in setting limits. Russia (2.4 $\mu W/cm^2$ for 900 MHz frequencies), China (6.6 $\mu W/cm^2$ for 900 MHz frequencies) and Italy (10 $\mu W/cm^2$ for 900 MHz frequencies) also more restrictive electromagnetic radiation frequencies (GSM Association (GSMA), 2013; Papmeletiou and del Pozo, 2005).

It is of great importance to carry out studies in indoor places where people spend most of their time, such as homes, schools or workplaces (Gryz et al., 2014; Koppel et al., 2019; Kottou et al., 2015; Zeghnoun and Dor, 2010). Numerous electronic devices radiate this type of electromagnetic waves such as mobile phones, WIFI devices or those that use Bluetooth technology. They are of great importance because the radiation received by neighbors is the summation at different frequencies. Some countries, such as Belgium, decided to limit exposure to RF – EMFs in children under the age of 16, eliminating Wi-Fi from preschool centres and forcing students to leave their mobile phones at home, thus avoiding an increase in radiation by these devices in the classroom (Iyare et al., 2019). According to a wide range of scientific articles, there is currently insufficient data to conclude the health effects of radiofrequency exposure in everyday life in the long term, thus confirming the need for studies that analyze health indicators with relative exposure rates (Röösli et al., 2010).

Most scientific articles dedicated to the study of the impact of radiation emitted by telephone antennas and health, study parameters related to cancer. In global figures, in 2018, according to the latest data available in the GLOBLOCAN (Global Cancer Observatory) project, cancer cases accounted for 18.1 million new cases (Globocan Observatory, 2019). According to the Spanish Society of Medical Oncology (SEOM), the number of cancer cases for 2020 is around 277,394 (Sociedad Española de Oncología Médica, 2020). The Spanish population is 47,100,396 people, therefore, out of the total population, the percentage of cancer cases is 0.6% (Instituto Nacional de Estadística, 2020).

The main objective of this study is to find a possible relationship, if any, between exposure to RF – EMFs with some health indicators such as sleep, headache and fatigue collected through surveys, using maximum electromagnetic radiation peak-to-peak measurements, without averaging values, in situ and in real – time through a spectrum analyzer and an isotropic antenna.

2. Methodology

The study was carried out at the request of a neighborhood association in Madrid (Colonia Fontarron, Vallecas) concerned about the proximity of the antennas to their homes. There was a meeting prior to the organization of the study in which the concerns of the neighbors were presented and served as a guide for the design of the study. Two phases can be distinguished: conducting health indicators surveys; and measurements register of RF electromagnetic radiation indoors and outdoors. The procedure to carry out the study is shown in Fig. 1. The geographical area has a total of 20 buildings towers with 13 floors each one that include four flats on each floor, except for the ground floor, where there are three flats. In addition to the towers, there are a total of 60 housing blocks, with 4 floors and two flats per floor, except on the ground floor where there are no houses. To estimate the total population, it was considered that four people lived in each house, obtaining a total of 5520.

The survey is own – designed (Table 1) and contains health indicators that may be sensitive to RF electromagnetic radiation, such as the presence of headaches, dizziness, parameters related to sleep and tiredness. In addition, the survey included questions about the prevalence of important diseases that the person surveyed could have suffered or was suffering from and the year they were diagnosed. A section was also included to indicate the time they have been living in the house. A total of 268 surveys were carried out during the months of June, July, August and September 2018, 174 results from the exposed area and 94 from the control area. Before starting the process, the information provided by the Ministry of Industry, Energy and Tourism, about the energy

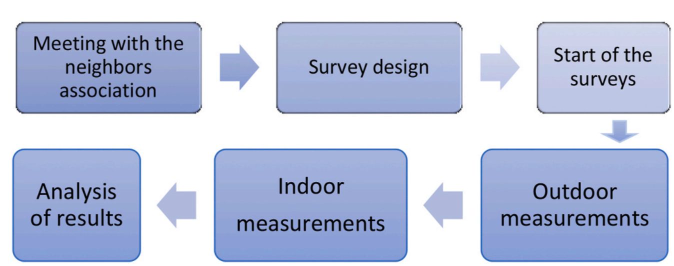

Fig. 1. Block diagram detailing the procedure carried out to do the study. The first step was to meet with the neighbors from which the first needs that the study must cover are extracted. Later, the area is studied and the areas to be surveyed and measured are selected. Once obtained the surveys, the outdoor and indoor measurements were made. Finally, the results were analyzed.

Table 1
Self - designed survey to evaluate some parameters that may be sensitive to electromagnetic radiation from radiofrequency electromagnetic fields. Moreover, it includes questions about the important diseases that the person surveyed could have suffered or was suffering from and the year in which they were detected.

HEADACHE	SLEEP	Fatigue interferes with my physical activity
Presence	Number of hours (hours per day)	Strongly disagree
No	1 to 2	Disagree
Yes	3 to 5	Little disagree
DKDA	6 to 8	Indifferent
Frequency	More than 8	Little agree
Weekly	DK/DA	Agree
Daily	Time it takes to fall asleep	Storngly agree
DKDA	Less than 15	DKDA
Existence of a specific pain location	15 min	Fatigue causes me frequent problems
No	30 min	Strongly disagree
Yes	1 h	Disagree
DKDA	More than 1 h	Little disagree
Location of pain	DK/DA	Indifferent
Front	Time it takes to get out of bed	Little agree
Back	Less than 15	Agree
Right	15 min	Strongly agree
Left	30 min	DKDA
Front and right	1 h	My tiredness prevents me from continued physical functioning
Front and left	More than 1 h	Strongly disagree
Front, right and left	DK/DA	Disagree
Left and right	Having nightmares at night	Little disagree
DK/DA	No	Indifferent
Intensity	Yes	Little agree
1 to 2	Waking up from nightmares	Agree
3 to 5	No	Storngly agree
5 to 7	Yes	DKDA
DK/DA	DK/DA	Fatigue interferes in the fulfillment of my responsabilities and duties
DIZZINESS	TIREDNESS	Strongly disagree
Presence	I'm less motivated if I'm tired	Disagree
Yes	Strongly disagree	Little disagree
No	Disagree	Indifferent
DK/DA	Little disagree	Little agree
Frequency (days per week)	Indifferent	Agree
1 to 2	Little agree	Strongly agree
3 to 5	Agree	DKDA
5 to 7	Strngly agree	Fatigue is one of my most disabling symptoms
DK/DA	DKDA	Strongly disagree
INSTABILITY	Exercise makes me tired	Disagree
Presence	Strongly disagree	Little disagree
No	Disagree	Indifferent
Yes	Little disagree	Little agree
DK/DA	Indifferent	Agree
Frequency (days per week)	Little agree	Strongly agree
1 to 2	Agree	DKDA
3 to 5	Strongly agree	Fatigue interferes with my work, family and social life
5 to 7	DKDA	Strongly disagree
DK/DA	I get tired easily	Disagree
TACHYCARDIA	Strongly disagree	Little disagree
Presence	Disagree	Indifferent
No	Little disagree	Little agree
Yes	Indifferent	Agree
Frequency (days per week)	Little agree	Strngly agree
1 to 2	Agree	DKDA
3 to 5	Strongly agree	
5 to 7	DKDA	
More than 7		
DK/DA		

radiation beam of the telephone base stations dose to Fontarrón neighborhood was analyzed. The information provided includes the frequency bands in which the base stations operate and the maximum exposure limits legally allowed. After studying the radiated area, the geographical study area was divided into two sections: area exposed to radiation and non – exposed area, used as a control, depending on the distance to the antenna nuclei (298.66 m and 32.78° degrees from the horizontal) and the main radiation lobe of each antenna. The radiation power density decreases inversely proportional to the distance, that is why the distance reference is taken to delimit the control area from the experimental area. The survey process was carried out by a different group of people than the one who carried out the measures in order not to bias the study and so that the responses of the residents of the study area were reliable and not subject to beliefs or interests regarding telephone antennas.

2.1. RF – EMF measurements

The measurements were divided into two periods. Between March, April and May 2019, the measurements were carried out outdoors, in the time slot from 11:00 a.m. to 1:00 p.m., always on the days corresponding to the weekend, Saturday and Sunday, because people spend more time at home. The indoor measurements of the exposed area were carried out in the first week of September 2019, in the time slot from 5:00 p.m. to 8:00 p.m. Those corresponding to the control homes were carried out in November 2019, in the same period of time.

The equipment used was a Rohde & Schwarz brand FSH8 spectrum analyzer. It has a wide frequency range of up to 8 GHz, covering all common wireless communication services, such as mobile radio (GSM, CDMA, UMTS, DECT and the upcoming LTE standard), Bluetooth, WLAN (IEEE 802.11a, b, g, n), Wimax TM and sound and television broadcasting. The equipment calibration was verified before use. In addition, a Rohde & Schwarz model TSEMF-B2 brand isotropic antenna was used in a bandwidth of 700 Mhz at 6 Ghz, registering peak measurements during a 10-min interval, attached to the spectral analyzer through a wooden tripod. The total procedure was carried out, with the approval of the board of the Vallecas district.

Nine antennas are registered in the information provided by the Ministry of Industry, Energy and Tourism. The first five antennas correspond to the right side of the analyzed area, located in the highest part of two 13-story towers. The remaining four, also located in two towers with the same number of floors, are located on the left side of the study area, with a distance between the pairs of towers of 438.26 m in a straight line. A total of 105 measurements of maximum levels of radiofrequency exposure were recorded in different places. For outdoor measurements, 50-m concentric circles were drawn around the radiation focus of the base stations, so there were finally 3–6 measurements per circle and four circles per focus, at distances of 0, 50, 100, and 150 m respectively. This distribution of measurements can be seen in Fig. 2 and Fig. 3. In the case of indoor measurements, three were made per tower and two per block at different heights. In the towers, the chosen floors corresponded to the highest floor, an intermediate floor and the portal, both homes fulfilled the condition of having previously completed the health indicators survey. In the case of the blocks, measurements were taken on the highest floor and in the hall, always fulfilling the condition already mentioned.

In this study, the regulations imposed by CENELEC are not followed. The difference is clear, measurements were registered in 10 min period,

Fig. 2. Color representation of the concentric measurement circles drawn on the antennas (0, 50, 100 and 150 m). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3. The study area is delimited in blue. The control area is highlighted in a green oval. In red circles, the two radiation foci are located. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

maximum peak, not average, so the data for the analysis of results only considers the peak values, the maximum radiation received by a person located at the measurement point.

2.2. Statistical methodology

For the statistical analysis of results, the SPSS IBM software was used. A binomial regression model is used for the yes/no questions of the health parameters survey, which correlates the data from the electromagnetic radiation power density measurements made in each household with the tenant's responses. For the remaining questions, a multinomial regression model is used. In the multinomial model, the radiation power density is divided into three groups: houses with low exposure (7–1775 μW/m^2), houses with medium exposure (>1775–3543 μW/m^2) and houses with high exposure (>3543–5311 μW/m^2). We calculated a crude model to derive the odds ratio (OR) and the corresponding 95% confidence interval (95% –CI), as well as the probability value (p-value) for the medium and high exposure data, taking the category low exposure for reference.

3. Results and discussion

3.1. Radiation results

After analyzing the results obtained with the measurements in situ, we obtained the radiation averages, the maximum peak and the maximum frequency at which the maximum peak occurred. In some cases, the maximum peak occurs at a frequency that is not recorded by the data provided by the ministry.

The results of the outdoor measurements show the highest value of radiation for both the mean of intensities in the summation of frequencies and the peak intensity with respective values of 556 μW/m^2 and 6700 μW/m^2 at 1810.48 MHz. The minimum is recorded with values 11 μW/m^2 and 48 μW/m^2 at 2155.40 MHz (Table 2).

In the area exposed to radiation, the indoor measurements give an average radiation of 5.73 μW/m^2, with maximum values of 5310 μW/m^2 at a frequency of 1768.41 MHz, 3593,12 μW/m^2 at a frequency of 943.97 MHz and 3100 μW/m^2 at a frequency of 5495.24 MHz (Table 3). In those carried out on the street, mean values of radiation intensity of 14.3 μW/m^2 and maximum peaks were found at frequencies of 809.36 MHz, 809.36 MHz and 962.38 MHz, with maximum power density values of 13,000 μWcm^2, 13,000 μW/m^2 and 9460 μW/m^2 respectively (Table 2). Regarding the control area, the mean radiation value for the indoor measurements is 1.18 μW/m^2. The maximum values are reached in 2260 μW/m^2 at a frequency of 1945.08 MHz, 332 μW/m^2 at a frequency of 1734.76 MHz, 240 μW/m^2 at a frequency of 1734.76 MHz (Table 4). In the measurements carried out on the street in the control area, an average radiation intensity of 1.68 μW/m^2 is obtained with maximum values of 2.24 μW/m^2, 2.18 μW/m^2 and 1.66 μW/m^2 at frequencies of 2130.15 MHz, 1860.95 MHz and 2146.98 MHz respectively (Table 2).

If the radiation peaks in the frequency band for WIFI emission are observed, only two of the homes obtain their maximum peaks at those frequencies.

3.2. Surveys results

The indicators studied were relative to headaches, dizziness, fainting, tachycardia, sleep habits and tiredness. The respondent's profile corresponds to a 60-year-old woman, for the exposed area; and a 56-year-old woman for the control area (Table 5).

The results show that 39.10% of the people state that they have headaches in the exposed area, compared to 25.50% in the control area. Most of these people report weekly headaches, both in the exposed area and in the control area (25.29% and 15.95% respectively). There is also a clear difference regarding pain intensity, which 23.56% describe as being of maximum intensity in the exposed area, compared to 5.3% in the control area. The latter, on average, report moderate headaches by 12.76%. The results in relation with headaches regarding the specific area of headache pain have been eliminated because they have very few answers and cannot be considered as sufficient data to include in the study.

If the data related to dizziness is considered, it can be observed that, in the exposure area over the total study population, 32.76% of people report having dizziness compared to a total of 21.27% who report having them in the control area. Regarding the frequency, in the exposed area, most people get dizzy every 1 or 2 days (14.37%) and every 3 or 5

Table 2
Radiation power density of outdoor measurements. The average, the maximum peak and the maximum peak frequency measurements are presented for each point. L: Measurements taken at the left focus of radiation antennas, R: Measurements taken at the right focus of radiation antennas.

Measurement	Average [μW/m^2]	Maximum peak [μW/m^2]	Maximum peak frequency [MHz]
Distance	0 [m]		
P1 R	1.332	233.688	809.37
P2 R	2.160	278.000	809.36
P3 R	14.341	1384.419	1818.89
P1 L	0.422	18.247	1760
P2 L	2.629	545.523	843.01
P3 L	15.887	1819.103	2660.15
Distance	50 [m]		
P4 R	15.581	5223.267	952.38
P5 R	18.050	2538.067	1827.3
P6 R	9.470	738.735	952.38
P13 R	18.553	2337.698	952.38
P5 L	15.255	1819.103	2660.15
P6 L	3.140	147.000	952.38
P7 L	4.550	525.000	1827.3015
P13 L	16.200	1820.000	2660.15
P4 L	7.770	525.000	1827.3
Distance	100 [m]		
P7 R	4.860	468.000	952.38
P8 R	1.770	140.000	1818.88
P9 R	72.400	13,000.000	809.365
P14 R	24.300	2880.000	1818.88
P16 R	35.910	3963.648	809.36
P 18 R	14.500	1750.000	809.36
P7 L	4.550	525.000	1827.3015
P 8 L	14.800	1820.000	2660.15873
P9 L	2.600	147.000	952.38
P14 L	16.500	1820.000	2660.15
P16 L	2.000	546.000	843.01
P18 L	3.440	218.000	2130.15
Distance	150 [m]		
P10 R	26.600	9460.000	952.38
P11 R	3.670	278.000	1810.47
P12 R	5.176	434.902	927.1428
P15 R	10.3	1480.000	809.36
P17 R	61.876	12,951.342	809.36
P10 L	11.189	1177.312	952.38
P11 L	12.500	1530.000	2660.15873
P12 L	1.470	139.000	2172.22
P15 L	16.803	1819.103	2660.16
P17 L	3.108	385.311	1852.53
Middle point	36.400	4640.000	1860.95
CONTROL			
P19	1.660	100.000	2146.98
P20	0.671	29.500	1860.95
P21	2.180	219.000	1860.95
P22	2.240	325.000	2130.15

days a week (11.49%). In the control area there is a majority with a difference around every 3 or 5 days. Regarding instability and fainting, a higher percentage of people also present instability in the exposed area (29.89%) compared to 19.15% in the control area. However, the same does not occur in the case of fainting, in which both groups report small affirmative percentages (5.74% and 7.40% respectively). Regarding the presence of tachycardias, the exposed group reported suffering from them by 27.60, compared to 12.78% of the control group.

In the sleep parameters, there is a clear majority of people who sleep in both areas, from 6 to 8 h a day (68.96% and 77.67% respectively). Although, an important percentage does it only from 3 to 5 h, 24.14% and 14.89% respectively. Most of the population takes around 15 min to get out of bed once awake, although this group receives a higher proportion in the control group (40.43%) than in the exposed group (32.20%). A similar percentage in both groups, it takes around 15 min to get out of bed (Exposed: 49.40%, control: 46.90%). 24.13% of the population say they have nightmares in the exposure area, compared to 12.77% who report having them in the control area.

Table 3
Radiation power density of indoor measurements. Both the maximum value and the frequency at which it is reached are displayed, as well as the average of the sum of the radiated power as a whole for all frequencies. The highest floors are represented by the value T - X. 3 or B - X.2 the floors with a medium height T - X.2 and the portals as T - X. 1 or B - X.1

Measurement	Average [μW/m^2]	Maximum peak [μW/m^2]	Frequency [MHz]
EXPOSED			
Distance	0 - 50 [m]		
T- 94.3	3.524	632.410	809.37
T- 94.2	1.983	92.044	2172.22
T - 94.1	4.354	2120.094	1776.82
T - 92.3	1.241	98.454	943.97
T - 92.2	27.925	3593.116	927.14
T - 92.1	0.916	154.536	1743.17
T - 1.3	16.630	2790.210	1818.89
T - 1.2	0.362	17.132	952.38
T - 1.1	5.913	1619.439	1776.83
T - 3.3	24.541	5311.496	1768.41
T - 3.2	1.036	103.356	5570.95
T - 3.1	2.375	427.067	843.02
Distance	50 - 100 [m]		
B - 90.2	18.254	3095.215	5495.24
B - 90.1	2.351	357.320	2441.42
B - 88.2	2.537	249.284	817.78
B - 88.1	1.476	223.701	809.37
B - 86.2	1.390	309.977	809.37
B - 86.1	0.724	151.164	809.37
T - 84.3	2.780	284.380	1852.54
T - 84.2	6.166	1172.953	2458.25
T - 84.1	0.907	135.735	1760.00
B - 4.2	2.574	907.512	2458.25
B - 4.2	0.688	58.400	2416.19
B - 4.1	1.422	442.830	1768.41
B - 156.2	0.291	7.747	952.38
B - 156.1	0.499	53.573	1768.41
Distance	100 - 150 [m]		
T - 82.3	10.135	2344.348	5268.10
T - 82.2	9.245	2226.814	2466.67
T - 82.1	0.522	78.979	1785.24
T - 98.3	38.482	2678.265	2121.75
T - 98.2	1.019	215.578	809.37
T - 98.1	0.514	46.581	5251.27
T - 96.3	47.070	3034.601	2660.15
T - 96.2	5.070	829.611	809.365
T - 96.1	4.371	1160.807	1768.41
B - 8.2	8.426	1511.560	885.08
B - 8.1	0.380	71.031	2533.97
T - 154.3	1.028	107.677	1827.30
T - 154.2	0.517	33.971	5217.62
T - 154.1	0.409	22.990	1894.60
Distance	150 - 200 [m]		
B - 10.2	0.412	81.348	2542.38
B - 10.1	1.030	155.855	1776.83
T - 152.3	5.386	787.739	2121.75
T - 152.2	3.867	1070.224	5217.62
T - 152.1	8.174	2263.485	1945.08
B - 12.2	0.476	16.412	2172.22
B - 12.1	0.486	62.545	834.60
Distance	More of 200		
B - 124.2	0.433	50.616	952.38
B - 124.1	1.058	115.603	952.38

Regarding the results obtained for fatigue, in all the statements the exposed area presents a higher percentage in the responses “Strongly agree” and “Agree” than the control area whose answers are more frequently “Disagree” or “Strongly disagree”.

All these results indicate a higher prevalence of suffering pathologies from the exposed group over the control group (see Fig. 4).

Regarding the results obtained from the responses registered on the important diseases, a total of 12 cases of cancer were obtained in the exposed area and 5 in the control area. One of the cases in the exposed area was eliminated as it was detected long before living in the area and it had been a short time living in the home. The total number of cases of

Table 4
Radiation of indoor control measurements. Radiation power density of indoor measurements. Both the maximum value and the frequency at which it is reached are displayed, as well as the average of the sum of the radiated power as a whole for all frequencies. The highest floors are represented by the value T - X. 3 or B - X.2 the floors with a medium height T - X.2 and the portals as T - X. 1 or B - X.1

Measurement	Average [μW/m^2]	Maximum peak [μW/m^2]	Maximum peak frequency [MHz]
T - 48.3	0.316	29.908	1734.7619
T - 48.2	0.278	12.528	809.365
T - 48.1	0.339	45.230	1768.4126
T - 50.3	1.058	239.981	1751.5873
T - 50.2	0.013	8.212	1860.95
T - 50.1	0.232	11.495	8934.92
T. 46 - 3	1.051	205.284	1734.76191
T. 46–2	0.832	170.226	2466.67
T. 46–1	1.125	216.074	1717.93
T. 44–3	1.467	331.742	1734.76
T. 44–2	0.389	15.671	1903.015
T. 44–1	8.174	2263.485	1945.08

Table 5
Epidemiological data obtained in the different study areas, exposure and control. The data are represented in terms of the sex of the subject and three age groups: under 20 years, between 20 and 40 years and over 40 years; all percentages are obtained over the total population surveyed, 268 people, for the exposed group n = 174 and for the control group n = 94.

	Exposed area (Frequency in %)	Control area (Frequency in %)
Men	28	11.5
Women	37	23.5
< 20 years old	2.6	3.4
20 years – 40 years old	17.15	14.2
>40 years old	45.15	17.5

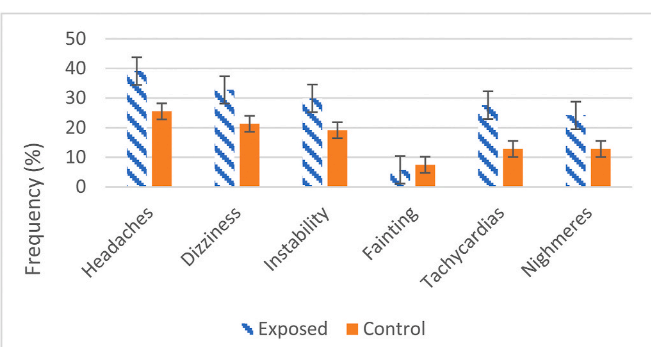

Fig. 4. Bar graph representing the frequency of appearance of the presence of parameters such as headaches, dizziness, instability, fainting, tachycardia and nightmares with 95% Cis error bars. The exposed area is represented in striped blue, the control in orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

cancer reported in total was 17.

3.3. Relationship between health indicators and electromagnetic radiation measurements

After analyzing the radiation results and the surveys separately, in order to establish a real relationship between the radiation rate and the responses of the polls the responses of the dwellings and the maximum peak radiation data obtained in each of them were selected.

Regarding the division by radiation intensity, for the binomial model

Table 6
Statistical results obtained through a linear binomial regression to relate the intensity of the radiation received and the health indicators. The OR values are presented, with a confidence level of 95% and the significance through the p - value. It is calculated a crude model.

Presence pathology	OR	95% - CI	P - value
Headache	7.50	1.63–36.64	0.010
Dizziness	2.18	0.72–6.62	0.171
Instability	1.30	0.36–4.74	0.829
Fainting	1.26	0.16–10.03	0.829
Tachycardias	1.59	0.48–5.22	0.448
Nightmares	7.30	1.53–35.98	0.001

(Table 6) are found high Odds Ratio values in three of the six measured parameters (presence of headaches, presence of nightmares, presence of dizziness), with values of small and statistically significant in two of them (headaches and the presence of nightmares).

For the multinomial model, in the medium value radiation intensities, observe high OR values in nine of the 18 studied values (headache intensity, frequency of dizziness, frequency of tachycardias, frequency of fainting, number of hours who sleeps a day, exercise tires me, my tiredness prevents continued physical exercise, fatigue interferes with my work, family and social life). In the case of high intensity values, high OR values are found in seven of the parameters under study (headache intensity, frequency of instability, frequency of fainting, number of hours you sleep a day, exercising me tired, my tiredness prevents continued physical functioning, tiredness interferes in my work, family and social life). In addition, for these values there are statistically significant values of p for six of the indicators (intensity of headaches, frequency of dizziness, number of hours you sleep a day, exercising tires me, my tiredness prevents continued physical function, tiredness interferes with my work, family and social life). Results are shown in Table 7.

In view of the results obtained, we can determine the existence of a relationship between the intensity of the electromagnetic radiation received and the change in some health indicators such as headaches, the presence and frequency of dizziness, number of hours a person sleeps daily, the presence of nightmares and tiredness, so it affects sleep parameters and other pathologies such as headaches, dizziness and tiredness.

3.4. Discussion

The results of the study should be analyzed in an appropriate context with respect to the results of other researchers and published articles, since there are no similar studies in terms of measurement methodology. In order to accurately compare exposure levels between or even within countries, it is vitally important to make comparable measurements, since a multitude of factors affect some radiation values or others. A study in Austria determined that the difference in radiation existing in rural areas and the city was evident (Hutter et al., 2006). And it not only depends on the location, but also on the measurement procedure and the equipment used for it. Risk assessment of radio frequency electromagnetic exposure has been hampered by the lack of reliable methods for studying it. Daily RF-EMF exposure exhibits great variability in spatial and temporal exposure patterns as it comes from a large number of different sources (Röösli et al., 2010). The rules regarding the measurement procedure established by CENELEC, based on criteria for evaluating the broadband averaged signal, are not adequate. The measurements should be obtained in narrow band, with maximum peak measurements of radiation intensity, since, by averaging the signal, relevant information is wasted on the real radiation to which the homes are exposed and, therefore, the people who they inhabit them day by day. It is also important to use equipment that measures electromagnetic radiation. A certain group of articles makes estimates of electromagnetic radiation through companies' telephone bills, without real

Table 7

Statistical results obtained through a binomial regression to relate the intensity of the radiation received and the health indicators. The OR values are presented, with a confidence level of 95% and the significance through the p - value. The radiation power density is divided into three groups: houses with low exposure (7–1775 μW/m^2), houses with medium exposure (>1775–3543 μW/m^2) and houses with high exposure (>3543–5311 μW/m^2). It is calculated a crude model taking the category low exposure for reference.

Health parameter	Power density of radiation 1775–3543 [μW/m^2]	p	>3543–5311 [μW/m^2]	p	P for the trend
	OR (95% - CI)		OR (95% - CI)		
Headache frequency	1.87 (0.84–4.15)	0.125	0.34 (0.051–2.30)	0.270	0.082
Headache intensity	5.95 (2.13–16.68)	0.001	7.52 (2.13–16.68)	0.012	<0.001
Dizziness frequency	2.59 (1.28–5.22)	0.008	0.96 (0.22–4.18)	0.959	0.011
Instability frequency	3.47 (0.89–13.62)	0.074	4.72 (1.03–21.64)	0.046	0.026
Taquicardyas frequency	2.01 (0.92–4.43)	0.082	1.03 (0.20–5.14)	0.976	0.193
Fainting frequency	3.00 (0.17–53.71)	0.455	12.00 (0.53–273.04)	0.119	0.312
Sleep					
Number of hours (hours per day)	68.05 (5.19–891.6)	0.001	12.45 (1.17–131.90)	0.036	<0.001
Time it takes to fall asleep	1.77 (0.71–4.41)	0.218	0.52 (0.11–2.43)	0.409	0.249
Time it takes to get out of bed	1.91 (0.70–5.25)	0.207	0.23 (0.026–2.00)	0.182	0.264
Tiredness					
I´m less motivated if I´m tired	0.76 (0.65–1.05)	0.092	0.44 (0.52–1.33)	0.439	0.168
Exercise makes me tired	14.81 (1.85–118.40)	0.011	6.69 (1.14–39.21)	0.035	<0.001
I get tired easily	1.12 (0.84–1.49)	0.438	0.99 (0.62–1.57)	0.960	0.726
Fatigue interferes with my physical activity	0.91 (0.66–1.27)	0.578	1.03 (0.63–1.68)	0.921	0.837
Fatigue causes me frequent problems	1.07 (0.76–1.50)	0.703	1.29 (0.76–2.20)	0.349	0.620
My tiredness prevents me from continued physical functioning	14.81 (1.85–118.40)	0.011	6.69 (1.14–39.21)	0.035	0.001
Fatigue interferes in the fulfillment of my responsabilities and duties	1.14 (0.81–1.60)	0.459	0.88 (0.49–1.58)	0.881	0.646
Fatigue is one of my most disabling symptoms	1.08 (0.80–1.48)	0.591	0.99 (0.61–1.63)	0.978	0.859
Fatigue interferes with my work, family and social life	12.80 (1.85–118.40)	0.011	6.69 (1.14–39.21)	0.035	<0.001

measurements, for example, a study carried out in Sweden and Finland uses records of mobile phone operators to estimate the time of call and relate it to headaches, for which they do not find statistically significant results (Auvinen et al., 2019), without carrying out measurements in real time and in situ. In addition to adjusting the data to the daily intake of analgesics, which is not correct. Recent publications ensure that there is a need for more multidisciplinary studies that consider the role of real environmental exposures and perception in relation to self-reported health outcomes (Fields and Emf, 2019; Gajšek et al., 2015).

Most studies on radiation rates indoors, study the radiation transmitted by WiFi sources, since nowadays both offices and homes tend to have a large number of sources of this type (Foster and Moulder, 2013). A study in Germany determined that 80% of the radiation to which people in a residential area in which electromagnetic field measurements were taken in 1348 homes were exposed, was due to radiation from WiFi devices (Breckenkamp et al., 2012). In the comparison between outdoor measurements and indoor measurements, we can assure that, in this case, the greatest contribution of radiation to which the neighbors undergo their dwellings corresponds to that radiated by the base telephone stations, since in only two households of the 38 studied obtained higher values for the WiFi frequency. This discrepancy with respect to what other studies assure, may be due to numerous factors.

After analyzing the results obtained in register radiation of the mobile base stations antennas and after studying the frequencies at which those antennas emitted according to the Ministry of Industry, Energy and Tourism, it is obtained frequencies that not appear in this information. This may be due to differences in the methodology carried out with respect to the measurement procedure. Specifically, nine of the measured outdoor points emit their radiation maximum at the frequency 809.37 MHz, which do not appear in the information provided.

In line with Bürgi et al. (2010) who found a low correlation between the distances to the base telephony antenna and the intensity of radiation exposed at small distances (Bürgi et al., 2008), in the present study, it has not been possible to relate the radiation detected in the different concentric circles with separation of 50 m drawn on the nuclei of the antennas, the radiation intensity depends fundamentally on the direction of the fundamental radiation beam and not so much on the distance from the telephone base stations. However, statistically significant differences have been found regarding the distance traced in the control and exposed areas. The severity of symptoms weakens for distances greater than 200 m from the foci of mobile phone base stations, which have radiation intensities on average 8 times less outdoors and 4 times less indoors, all values being except for one of the measurement points less than 1000 μW/m^2. Even with all this, we can see in the data obtained that the control area is not free of radiation. Although the radiation rate at which the population living in the houses delimited by the control area is found is lower, they are not free to receive radiation.

Most scientific articles dedicated to the study of the impact of radiation emitted by telephone antennas and health, study parameters related to cancer. Out of the total study population, 5.6% of cancer cases appear, with a total of 17 registered cases, which refers to a percentage almost 10 times higher than that of the total Spanish population, which is 0.6%. In this study, conclusive data on the development of this pathology could not be extracted since the number of cases that occur in the control area and the exposed area are few with respect to the total population. In addition, for the study of these pathologies, a control over time and cellular studies must be carried out that can relate the appearance of this pathology to the electromagnetic waves produced by the radiation of telephone antennas.

From all the indicators shown in the survey model (Table 1), after the analysis of results carried out in relation to the radiation rate at which the respondents were with a value of $p < 0.05$, a statistically significant relationship is obtained with the presence of headaches (0.010) and their intensity (<0.001), the frequency of instability (0.026) the hours a person sleeps a day (<0.001) and the presence of nightmares (<0.001), in addition to three of the nine statements studied regarding fatigue, corresponding to "Physical exercise tires me" (0.001), "Fatigue interferes with my physical functioning" (<0.001) and "Fatigue interferes with my work, my family and my social life" (<0.001). Furthermore, a high correlation is obtained, with high OR values, although not statistically significant results for the presence of dizziness (0.171) and the frequency of fading (0.312). However, the existence of a relationship cannot be affirmed for other factors such as the presence of instability (0.829), the presence of fading (0.829) or tachycardias (0.448) and the exposure rate. Neither for certain sleep parameters such as the time it takes to fall asleep once they are in bed (0.249) or the time it takes to get up once they wake up (0.264), in addition to the remaining six parameters that assess tiredness. A Spanish article from 2004 refers to certain similarities with our study, pointing to factors such as fatigue and sleep disorders as the strongest associations between pathologies and radiation measurements, in addition to showing that another of the symptoms with the highest correlation with exposure to radiation are headaches (Navarro et al., 2003; Oberfeld et al., 2004). Other studies also confirm the existence of a relationship between suffering from headaches and the radiation index to which the population is exposed (Abdel-Rassoul et al., 2007; Breckenkamp et al., 2012; Bürgi et al., 2008; Foster and Moulder, 2013; Hutter et al., 2006; Röösli et al., 2010). Regarding fatigue, an Egyptian study found a correlation between the fatigue felt by the study population with respect to the intensity of radiation they received (Abdel-Rassoul et al., 2007). In general, the studies, contrary to the results found in this study, found no relationship between levels of exposure and the presence of dizziness or affected sleep factors (Abdel-Rassoul et al., 2007; Auvinen et al., 2019; Hinrichs et al., 2005; Hutter et al., 2006).

This article does not intend for the results to be generalizable since there is always a certain population bias. It is necessary for the authorities to carry out population epidemiological studies that reassure those whose homes are close to the antennas and ensure that people's health is not subject to risks, respecting the radiation regulations and location of base telephone structures. The absence of scientific evidence forces the need for large-scale studies to determine if the technologies can pose a risk to people's health before they are launched on the market. It is of great importance to study the short-term effects such as headaches, dizziness, sleep parameters and those symptoms that could be related to prolonged exposure to mobile phone antennas. The new 5G technology will require the installation of many smaller cell and antenna towers, which operate at a higher power than the existing ones, so exposure evaluations are particularly necessary both inside homes and in the outdoor (Miller et al., 2019).

4. Conclusion

In conclusion, the data obtained shows that there is a relationship between the power density of radiation that a person receives at home every day and the presence of headaches, as well as the presence of sleep disorders. People who receive higher doses of radiation sleep less hours and have nightmares at night. In addition, these people suffer from headaches with greater intensity and are more prone to dizziness. In this study, indicators like fainting episodes, presence of tachycardias or instability cannot be related. No conclusive results were found for fatigue, since, out of nine parameters studied, only a statistically significant relationship was found in three of them. The study of how electromagnetic fields affect health, should not only be done in relation to cancer, but also health indicators related to day to day.

The methodology for obtaining electromagnetic radiation measurements should be reviewed, the averaged radiation measurements that are described in the CENELEC standard are not the most appropriate, they should be carried out in a narrow band and with maximum peak measurements.

The measured intensity depends fundamentally on the direction of the fundamental radiation beam and not so much on the distance to the antenna. In the beam direction, differences are found in the presence of pathologies with respect to distances, when these are greater than 200 m. Even at this distance, the population continues to receive radiation peaks, so that no one is free from exposure to these radiation sources.

The need for this study is related to the situation before 5G in terms of electromagnetic radiation rates. This study may be compared with the new radiant procedures that will be adopted in a short time.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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