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Health disturbances and exposure to radiofrequency electromagnetic fields from mobile-phone base stations in French urban areas

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ABSTRACT

The effects of radiofrequency exposure on the health of people living near mobile-phone base stations (MPBSs) have been the subject of several studies since the mid-2000s, with contradictory results.

We aimed to investigate the association between measured exposure to radiofrequency electromagnetic fields (RF-EMF) from MPBSs and the presence of self-reported non-specific and insomnia-like symptoms.

A cross-sectional survey conducted between 2015 and 2017 in five large cities in France involved 354 people living in buildings located at a distance of 250 m or less from an MPBS and in the main transmit beam of the antennas. Information on environmental concerns, anxiety, and non-specific and insomnia-like symptoms was collected with a questionnaire administrated by telephone. A complete broadband field-meter measurement [100 kHz - 6 GHz] was then made at five points of each dwelling, followed by a spectral analysis at the point of highest exposure, detailing the contribution of each service, including MPBS.

The median exposure from MPBS was 0.27 V/m (0.44 V/m for global field), ranging from 0.03 V/m to 3.58 V/m, MPBSs being the main source of exposure for 64% of the dwellings. In this study population, the measured exposure from MPBSs was not associated with self-reported non-specific or insomnia-like symptoms. However, for insomnia-like symptoms, a significant interaction was found between RF-EMF exposure from MPBSs and environmental concerns.

These findings do not support the hypothesis of an effect of RF-EMF from MPBSs on non-specific or insomnia-like symptoms in the overall population. Studies are needed to further investigate the positive association observed between exposure from MPBSs and insomnia-like symptoms among people reporting environmental concerns.

Credit author statement

The study was conceived by a working group from the Dialog Committee "Radiofrequencies and health" of the French Agency for Food, Environmental, and Occupational Health & Safety (ANSES), and a Scientific Council (Jean-François Doré, Pierre Ducimetière, Anne-Sophie Evrard, Thierry Letertre) followed its implementation, and reviewed the results as they progressed and the writing of the manuscript. Claire Ségala, Jean-Christian Genier, Sylvie Martin and Pascal De Giudici designed the study. Jean-Christian Genier was responsible for the EMF measurements and for the coordination of the home visits. Sylvie Martin, Pascal De Giudici and Etienne Cassagne were responsible for data management and processing and statistical analysis. Sylvie Martin was responsible for editing the manuscript, with the help of Claire Ségala, Jean-Christian Genier and Pascal De Giudici. A declaration has been made to the French data protection authority (number 1862114)

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1. Introduction

Wireless technologies, such as mobile phones, have emerged over the last two decades and the number of mobile phone base stations (MPBSs) has grown rapidly, particularly in urban areas. These sources of radiofrequency electromagnetic fields (RF-EMF) produce low but continuous exposure for nearby populations, who are often more concerned about the health effects from these environmental RF-EMF sources than those from the use of mobile and cordless phones (LINK, 2014). In such situations, certain individuals who define themselves as electromagnetic hypersensitive (EHS) have reported non-specific symptoms, such as fatigue, headaches, auditory symptoms, skin sensations, musculoskeletal pain, concentration problems, nervousness, and insomnia-like symptoms (Balaitsas et al., 2014). Very little is known about how these health complaints are related to RF-EMF exposure and/or to the fear of negative effects (i.e. nocebo effect) from MPBSs (Röösli, 2008; Röösli et al., 2010; Rubin et al., 2010; ANSES, 2013).

In most cases, experimental studies have only considered health effects related to short-term exposure in small subgroups. However, an experimental field study was conducted that investigated the effects of short-term radiofrequency exposure from MPBSs on the objective and subjective sleep of 397 residents (Danker-Hopfe et al., 2010). Epidemiological studies investigated associations between long-term exposure and outcomes in larger samples of nearby populations living under normal conditions (Hutter, 2006; Thomas et al., 2008; Berg-Beckdhoff et al., 2009; Heinrich et al., 2011; Mohler et al., 2012; Frei et al., 2012; Balaitsas et al., 2015, 2016; Martens et al., 2017). Most did not find any significant association between such exposure and health effects. However, exposure levels in these studies were low, with little difference between participants. Indeed, exposure assessment is still a major challenge. Several of these studies performed individual exposure measurements (Thomas et al., 2008; Berg-Beckdhoff et al., 2009; Heinrich et al., 2011; Mohler et al., 2012), but such measurements are costly and time-consuming for participants (Viel et al., 2011) and the use of an exposimeter could modify the participants' exposure behavior. Other studies used exposure prediction models (Mohler et al., 2012; Frei et al., 2012; Balaitsas et al., 2015, 2016; Martens et al., 2017). Such prediction models may have several limitations that can lead to potential exposure error and misclassification (Balaitsas et al., 2015). Finally, other studies used spot measurements using sophisticated devices, such as a spectrum analyzer (Hutter, 2006; Berg-Beckdhoff et al., 2009; Tomitsch and Dechant, 2015). They have been shown to be an appropriate exposure proxy (Frei et al., 2010). Furthermore, in France, such measurements follow a standardized protocol and are performed in the framework of campaigns undertaken in establishments serving the public and at the request of residents by the National Agency of Frequencies (ANFR), (ANFR, 2017).

In this context, epidemiological research is still necessary to investigate the possible association between measured RF-EMF emissions from MPBSs and health disturbances. We thus conducted a cross-sectional study in five large cities in France to investigate the association between radiofrequency exposure from MPBSs as measured in the participants' homes and the presence of self-reported non-specific and insomnia-like symptoms.*

2. Material and methods

2.1. Participants and protocol survey

Participation in the study was proposed to adults (18 years of age or older) living in five large cities of metropolitan France and their immediate surroundings (Paris, Antony, Lyon, Lille, and Angers). They were selected according to a protocol detailed elsewhere (De Giudici et al., 2020). First, MPBSs were selected based on having been in operation for more than two years and not having been the subject of complaints by local residents at the time of their installation. Then, buildings located at a distance of 250 m or less from the MPBSs and in the main transmit beam of the antennas were identified. The sampling frame corresponded to a list of households within these buildings for which the fixed-line phone numbers were available in a telephone directory. A letter from the French Agency for Food, Environmental, and Occupational Health & Safety (ANSES) was sent to these households to present the study entitled "Study on the Relationships between Health and the Urban Environment". This letter informed the residents that they would receive a call from a survey institute to complete a questionnaire (duration: 15–20 min) and schedule an appointment to carry out exposure measurements at their home, without specifying their nature. The telephone survey was held between late 2015 and mid-2017, depending on the city. The eligibility criteria to participate in the study were being 18 years of age or older, being able to respond to a questionnaire, and having lived for at least six months in the selected dwelling that must be the main residence of the participant. When they were more than one eligible person in a household, a random draw of the person to be included was made among those who met the eligibility criteria. At the end of the interview, the type of home measurement was revealed and a time slot to conduct it was decided in consultation with the participant.

2.2. Health outcomes

The Electromagnetic Hypersensitivity Questionnaire, assessing 57 non-specific symptoms, was used (Eltiti et al., 2007a). The symptoms commonly reported by EHS individuals are all non-specific and, to a certain degree, occur naturally in the general population. It is not that EHS individuals experience unique symptoms or even unique symptom patterns, but rather they experience such symptoms to a greater, sometimes even debilitating, degree than most people in the general population (Eltiti et al., 2007a). In this questionnaire, participants indicated how much they were suffering from each symptom using a five-point Likert scale: (0) « not at all », (1) « a little », (2) « moderately », (3) « quite a bit », or (4) « a great deal ». Rare missing responses for a symptom were classified as "not at all", allowing calculation of a symptom score for all participants. A validation study has been conducted using principal component analysis with direct oblimin rotation, showing individual symptoms to be consistently grouped in cohesive symptom categories (data not shown) (Eltiti et al., 2007a; Hojo et al., 2016). An "overall symptoms score" was calculated according to the methodology proposed by Eltiti et al. (2007a), by summing the intensity of the 57 symptoms. The overall symptoms score can therefore vary between 0 and 228 (a score equal to 228 corresponding to the highest intensity for all symptoms).

The presence of insomnia-like symptoms (yes/no) was defined as having at least one of the following four disorders: (i) difficulty in falling asleep,(ii) waking up at night, (iii) waking up too early in the morning, (iv) non-recovering sleep, for more than three nights a week, for at least one month, and with repercussions on daily life (Beck et al., 2012).

2.3. Sociodemographic and other health characteristics

Information on the socio-demographic characteristics of participants and smoking status (smokers/nonsmokers) was collected. Self-perceived health (five-point Likert scale) and chronic conditions (yes/no) were measured by the two first questions of the Minimum European Health Module (Cox et al., 2009). Anxiety was assessed by the score of the corresponding dimension from the revised French version of the Symptom Check List in 90 items (min = 0, max = 4) (Derogatis et al., 1973).

2.4. Environmental concerns

Participants were asked to answer questions related to their perception of the general environment (five questions) and perceived health risks (five questions) and level of information concerning the health risks (five questions) for five types of environmental exposure: outdoor air pollution, indoor air pollution, noise, use of chemicals, and radiofrequencies. These questions were all drawn from a French questionnaire on environmental risk perception (Menard et al., 2008). A typology of respondents based on their answers to these 15 questions was then completed using principal component analysis (a method that is able to "summarize" information from a large number of variables), followed by hierarchical clustering (a method that allows individuals to be categorized into groups with maximum intra-group homogeneity and maximum inter-group heterogeneity). Finally, three groups were identified, reflecting three different attitudes towards the general environment: "worried" participants, those who were "slightly concerned", and those who identified themselves as "uninformed".

For each of the five types of environmental exposure (outdoor air pollution, indoor air pollution, noise, use of chemicals, and radiofrequencies), participants were asked whether they attributed or not their self-reported symptoms to such exposure using a six-point Likert scale: « do not know », « not at all », « a little », « moderately », « quite a bit », « a great deal ». This question on the attribution of reported symptoms to electromagnetic fields was issued from the Electromagnetic Hypersensitivity Questionnaire (Eltiti et al., 2007a). A computer bug resulted in theses question not being asked of 27 participants who expressed having symptoms.

2.5. Exposure assessment

The full protocol defined by the National Frequency Agency (19 ANFR DR15-4) for spot measurement is detailed elsewhere (De Giudici et al., 2020). In the first step, a trained technician carried out a complete broadband field-meter measurement on a wide range of frequencies [100 kHz - 6 GHz] in each dwelling at five points presumably located in the most exposed areas. The second step consisted of conducting a spectral analysis to detail the contribution of each service (TV, radio, mobile phone, etc.) at the point of highest exposure among the five previous points. During his visit, the technician also collected information on the technical characteristics of the dwelling, appliances, location of the dwelling in relation to the MPBS, and visibility of the base station included in the study from the dwelling.

RF-EMF were classified into two categories according to the emitting source: (i) those emitted by MPBSs, i.e. downlink LTE, GSM, and UMTS, and (ii) "other RF-EMF". The root mean square (RMS), expressed in V/m, was used for both types of exposure and for all measured continuous values. The frequencies used by uplinks were excluded, the objective of the study being the background RF-EMF of the MPBS and not the RF-EMF of the mobile phone itself.

2.6. Main statistical analyses

Descriptive analyses were initially performed to obtain an overview of the distribution of the participants' socio-demographic characteristics, health outcomes, and attitudes towards the general environment. Socio-demographic characteristics were compared to those of French urban units of more than 200,000 inhabitants (INSEE, 2015) and those of the respondents to the phone questionnaire who did not accept the home exposure measurements. Chi2-tests were used to assess bivariate associations between insomnia-like symptoms and anxiety, attitudes, and attribution, whereas t-tests were used to compare the means of the overall symptoms scores between the strata of the same covariates.

RF-EMF indicators were also described according to the characteristics of the dwellings.

Given the hierarchical structure of the data (as several participants could live in the vicinity of the same MPBS), preliminary multilevel analyses using a random effect regression model were performed but showed no substantial clustering.

Multiple linear and logistic regression were respectively carried out to study the association between RF-EMF exposure from MPBSs and the continuous overall symptoms score and the binary insomnia-like symptoms variable. As the distribution of the overall symptoms score was not Gaussian, a log transformation was carried out to meet the conditions for the use of a linear model. Regression coefficients or odds ratios (OR) and their 95% confidence intervals (CIs) were estimated. ORs are presented for an increase in the level of exposure of one interquartile of the exposure variable.

The association between RF-EMF exposure from MPBSs and health outcomes was first examined (model 1) after adjustment for a core set of potential confounders selected using the backward stepwise selection procedure: age, gender, marital status, minor child at home, education, socio-professional category, professional status, current smoking, self-perceived health, chronic conditions, and other RF-EMF. At each stage, the variable with the highest non-significant p-value (i.e. $p > 0.05$) was removed. Age, gender, and socio-professional category were systematically retained, as well as variables for which the removal resulted in a large variation (>25%) of the coefficient measuring the association between the exposure variable and health outcomes. After this selection procedure, the variables related to anxiety and attitudes towards the general environment were entered into the model (model 2) to be tested as potential independent predictors of health outcomes. If there was a significant association with the outcomes, an interaction term was finally added to the model to test whether anxiety and attitudes towards the general environment modify the association between RF-EMF exposure and each of the health outcomes.

2.7. Sensitivity analysis

The association between RF-EMF exposure and each of the health outcomes was tested by including additional variables, each in turn, such as city, floor, and visibility of the MPBS from the dwelling, by stratifying the study population according to the visibility of the MPBS, by replacing the variable "attitudes towards the general environment" with the variable "attribution of health disturbances to radiofrequencies".

All statistical analyses were carried out using SAS (9.4) and R (3.3.2).

3. Results

3.1. Study population

Among the 2641 people contacted, 460 responded to the telephone survey (participation rate: 17%). Finally, 354, residing in the vicinity of 180 distinct MPBSs, also accepted home exposure measurements and were included in the study.

The characteristics of the study participants are presented in Table 1. On average, the participants were 53 years old. Relative to the French urban population, women, higher socio-professional categories, and retired people were highly represented, accounting for 59.9% (vs. 52.8%), 38.4% (vs.28.6%), and 33.9% (vs. 22.6%) of the participants, respectively. Overall, the sociodemographic and health characteristics of the participants were similar to those of the respondents to the phone questionnaire who did not accept the home exposure measurements (Table 1). However, the proportion of single people and those with at least "two years of higher-level education" was higher among the 354 participants (55.9% versus 42.5%, and 63.4% versus 47.6%, respectively).

The average score for anxiety was 0.24, with 55% of people having a null score (no anxiety) and only one participant with the maximal score. Concerning the attitudes of the participants towards the general environment, the responses of participants to the 15 questions on

Table 1
Comparison between the characteristics of the study participants and those who refused home measurements.

Characteristics	Study participants N = 354[a]	No home measurement N = 106[b]	p
Female gender (%)	59.9	67	0.15
Marital status (%)			0.03
Single	55.9	42.5	
With a partner	18.4	23.8	
Separated, divorced	17.2	16.0	
Widowed	8.5	13.2	
With minor child at home (%)	34.2	24.5	0.06
Education (%)			0.05
No diploma	5.4	9.7	
Less than high school level	20.6	30.1	
High school level	10.6	12.6	
Two years of higher education level	15.7	14.6	
Higher vocational or university level	47.7	33	
Socio-professional category[c] (%)			0.12
Workers and employees	43.8	54.8	
Intermediate professions	17.8	12.5	
Managers, researchers, and professionals	38.4	32.7	
Professional status (%)			0.19
Employed	51.4	49.5	
Unemployed	14.7	15.3	
Retired	33.9	35.2	
Current smoking (%)	18.6	15.2	0.42
Self-perceived health (%)			0.53
Very good/Good	19.8	21.7	
Fair	63.5	66	
Bad/Very bad	16.7	12.3	
Chronic condition (%)	36.7	30.5	0.24
Attitudes towards the general environment (%)			
Slightly concerned	54.1		
Worried	36.3		
Uninformed	9.6		
Insomnia-like symptoms (%)	19.4	19.2	0.96
Attribution of symptoms to EMF (%)			0.53
Not at all	26	25.5	
A little	5.3	10.6	
Moderately	10.8	12.8	
Quite a bit	9.3	7.4	
A great deal	3.7	3.2	
Does not know	44.9	40.4	
Age: mean (min, median, max)	53.4 (22, 54, 93)	53,6 (22, 52, 93)	0.92
Anxiety score: mean (min, median, max)	0.24 (0, 0, 4)	0.22 (0, 0, 4)	0.66
Overall symptoms score: mean (min, median, max)	24.6 (0, 18, 132)	23.7 (0.17, 5, 146)	0.73

[a] Missing values (n): 4 for education, 1 for self-perceived health, 10 for attitudes towards the general environment, 4 for insomnia-like symptoms, 31 for attribution of symptoms to EMF.
[b] missing values n): 3 for education, 2 for socio-professional category, 1 for professional status, 1 for chronic condition, 2 for insomnia-like symptoms, 12 for attribution of symptoms to EMF.
[c] In case of missing values for the social professional category (4%), participants were classified according to their education as follows: high school level or less as workers and employees, two years of higher education as intermediate profession, higher vocational or university level education as managers, researchers, and professionals.

environmental perceptions are presented in Table 2. The classification based on the answers to these 15 questions distinguished between 36.3% who were "worried", 54.1% who were "slightly concerned", and 9.6% who were "uninformed" about the general environment. For the risks associated with radiofrequencies, participants were most likely to declare "not knowing" than for other types of exposure (23.7% versus less than 7%) and the proportion of participants declaring themselves "uninformed" about this type of risk reached 60.4%.

Table 2
Environnemental perceptions.

		N = 354
Satisfaction with the place of residence (%) [a]	*Mostly satisfied*	85.0
	Mostly unsatisfied	15.0
Concern about environmental quality (%)	*Not at all*	20.3
	A little	26.9
	Moderately	32.5
	A great deal	20.3
Concern about the effect of the environment on health (%)	*Not at all*	22.9
	A little	26.1
	Moderately	28.9
	A great deal	22.1
Consultation with a doctor in connection with pollution (%)	*Never*	68.9
	Rarely	10.5
	Sometimes	14.4
	Very often	6.2
Thinking about moving because of the environment (%)	*Never*	63.6
	Rarely	7.3
	Sometimes	19.2
	Very often	9.9
Perceived health risks due to outdoor pollution (%)	*Very high*	31.4
	Mostly high	56.8
	Low	9.0
	Close to zero	1.4
	Does not know	1.4
Perceived health risks due to the use of chemicals (%)	*Very high*	15.3
	Mostly high	49.1
	Low	25.7
	Close to zero	4.5
	Does not know	5.4
Perceived health risks due to noise (%)	*Very high*	15.0
	Mostly high	49.1
	Low	27.5
	Close to zero	5.9
	Does not know	2.5
Perceived health risks due to indoor pollution (%)	*Very high*	15.0
	Mostly high	45.4
	Low	27.4
	Close to zero	5.4
	Does not know	6.8
Perceived health risks due to radiofrequencies (%)	*Very high*	19.5
	Mostly high	38.1
	Low	13.6
	Close to zero	5.1
	Does not know	23.7
Level of information on outdoor pollution (%)[c]	*Mostly well informed*	45.0
	Mostly uninformed	50.7
	Never heard about	4.3
Level of information on the use of chemicals (%)[a]	*Mostly well informed*	50.7
	Mostly uninformed	42.5
	Never heard about	6.8
Level of information on noise (%)[c]	*Mostly well informed*	31.6
	Mostly uninformed	54.4
	Never heard about	14.0
Level of information on indoor pollution (%)*[b]	*Mostly well informed*	21.6
	Mostly uninformed	64.5
	Never heard about	13.9
Level of information on radiofrequencies (%)	*Mostly well informed*	24.3
	Mostly uninformed	60.4
	Never heard about	15.3

[a] 1 missing value.
[b] 2 missing values.
[c] 3 missing values.

Among the study participants, 44.9% did not know whether their self-reported symptoms (at least one) were related to RF-EMF or not, 31.3% reported little or no attribution, 23.8% reported an attribution (moderate, quite a bit, a great deal), and responses were missing for 31 individuals.

Overall, 19.4% of the participants reported insomnia-like symptoms. This prevalence increased significantly with anxiety (31% for an anxiety score > 0 vs. 9.7% for an anxiety score = 0), with attitudes toward the general environment (28.8% for the "worried" group, 13.6% for the "slightly concerned" group and 12.5% for the "uninformed" group), and with attribution of their self-reported symptoms to RF-EMF (32.9% for those who reported attribution, 11.9% for those who reported little or no attribution, and 21.8% for those who didn't know).

On average, the participants reported 14 non-specific symptoms and six symptoms were cited by more than 50%: fatigue (65.8%), back pain (61.2%), dry skin (55%), sleep disturbances (52.5%), stress (52.5%), and anxiety (51.4%). Only, four participants reported no symptoms. The mean overall symptoms score was 24.6 (range: 0–132). The mean also increased significantly with anxiety (36.2 for an anxiety score > 0 vs. 25.3 for an anxiety score = 0), with attitudes toward the general environment (36.2 for the "worried" group, 17.8 for the "slightly concerned" group, and 20.3 for the "uninformed" group), and attribution of their self-reported symptoms to RF-EMF (37.4 if they were attributed, 15.7 if there was little or no attribution, and 27.8 for those who didn't know).

3.2. Exposure to RF-EMF from MPBSs

MPBSs were the main source of exposure for 64% of households based on the measurement performed at the point of highest home exposure. The median exposure at this point was 0.27 V/m, ranging from 0.03 V/m to 3.58 V/m, with an interquartile range of 0.396 V/m (Table 3).

Exposure increased with the size of the city, higher floor of the building, whether the dwelling was in front of the MPBS, and whether it was considered to be visible from the dwelling by the technician (Table 4). More details are provided elsewhere (De Giudici et al., 2020).

3.3. Statistical analyses of the association between RF-EMF exposure from MPBSs and health outcomes

Results of the analysis are presented in Table 5. Both outcomes increased significantly with anxiety, whereas only the overall symptoms score was significantly higher in the "worried" than in the"slightly concerned" group.

We found no significant association (model 2) between RF-EMF exposure from MPBSs and the overall symptoms score ($\beta = -0.01$, 95%CI: 0.018-0.15) nor between RF-EMF exposure from MPBSs and insomnia-like symptoms (OR = 1.22, 95%CI: 0.96–1.54).

3.4. Interaction analyses

There was a statistically significant interaction between RF-EMF exposure from MPBSs and attitudes towards the general environment solely in the model related to insomnia-like symptoms. The association between RF-EMF exposure and insomnia-like symptoms was stronger for the "worried" about the general environment (OR = 1.80, 95%CI: 1.14–2.84) and the "uninformed" (OR = 2.12, 95%CI: 1.05–4.26) participants than for the "slightly concerned" participants (OR = 0.84, 95% CI: 0.55–1.31) (Table 6).

Table 4
RF-EMF exposure from MPBSs according to housing characteristics.

	RF-EMF exposure from MPBS (V/m)				
	$N_{housing}$	Mean (sd)	Minimum	Median	Maximum
City (city pop./metropolitan pop.)[a]					
Antony (61,711/ 7,026,765)	25	0.37 (0.27)	0.05	0.33	1.32
Angers (151,520/ 228,550)	46	0.24 (0.19)	0.03	0.17	0.72
Lille (232,741/ 493,214)	85	0.42 (0.46)	0.05	0.22	2.23
Lyon (516,092/ 2,326,223)	106	0.39 (0.42)	0.03	0.23	2.11
Paris (2148,000/ 7,026,765)	92	0.59 (0.65)	0.04	0.38	3.58
Floor[b]					
0	45	0.20 (0.28)	0.03	0.10	1.63
1	43	0.23 (0.26)	0.03	0.11	1.25
2	49	0.28 (0.26)	0.04	0.18	1.12
3	56	0.42 (0.42)	0.05	0.30	2.18
4	38	0.44 (0.46)	0.03	0.30	2.23
5	38	0.42 (0.44)	0.07	0.25	2.04
≥ 6	83	0.75 (0.65)	0.09	0.54	3.58
Orientation[c]					
Front of the MPBS	152	0.62 (0.62)	0.03	0.45	3.58
Other	198	0.29 (0.27)	0.03	0.21	1.54
Visibility of the MPBS[d]					
Yes	117	0.71 (0.64)	0.05	0.48	3.58
No	236	0.29 (0.30)	0.03	0.18	2.11

[a] French census.
[b] 2 missing values.
[c] 4 missing values.
[d] 1 missing value.

3.5. Sensitivity analyses (Tables 6 and 7)

The risk of insomnia-like symptoms related to RF-EMF exposure of "worried" participants about the general environment remained significant when the city, floor of the building, and visibility of the MPBS were each included in turn, in the final interaction model: the OR was 1.75 (95% CI: 1.10–2.78), 1.64 (95% CI: 1.02–2.61), and 1.81 (95% CI: 1.13–2.90), respectively. The risk of insomnia-like symptoms related to RF-EMF exposure of "uninformed" participants was less stable, with larger confidence intervals.

The association between RF-EMF exposure from MPBSs and insomnia-like symptoms for participants "worried" about the general environment was stronger and significant when the MPBS was "not visible" (OR = 2.47, 95% CI: 1.21–5.03) than when it was "visible" (OR = 1.36, 95% CI: 0.62–2.98). The risks were not significant for "uninformed" participants for either case.

Table 3
Description of RF-EMF exposure.

	RF-EMF exposure (V/m)					
	Mean (sd)	Minimum	1st quartile	Median	3rd quartile	Maximum
Total sources	0.58 (0.47)	0.16	0.29	0.44	0.68	3.64
MPBS sources	0.43 (0.48)	0.03	0.12	0.27	0.52	3.58
Other sources	0.30 (0.21)	0.15	0.18	0.23	0.34	2.28

Table 5
Results of the main multiple analyses on the association between RF-EMF exposure from MPBSs and health outcomes.

	Insomnia-like symptoms				Overall symptoms score			
	Model 1[a] (N = 349)		Model 2[b] (N = 340)		Model 1[c] (N = 353)		Model 2[d] (N = 343)	
	OR[e] (95% CI)	p	OR[e] (95% CI)	p	β (95% CI)	p	β (95% CI)	p
EMF exposure from MPBS	1.15 (0.92; 1.43)	0.21	1.22 (0.96; 1.54)	0.10	−0.06 (−0.25; 0.12)	0.50	−0.01 (−0.18; 0.15)	0.87
Score of anxiety (for one-point increase)			3.72 (1.85; 7.49)	$<10^{-3}$			0.79 (0.61; 0.97)	$<10^{-4}$
Attitudes towards general environment								
Slightly concerned			–				–	
Worried			1.65 (0.82; 3.32)	0.16			0.30 (0.11; 0.48)	0.002
Uninformed			0.74 (0.22; 2.53)	0.64			−0.11 (−0.39; 0.18)	0.46

[a] Logistic regression model including age, gender, socio-professional category, self-perceived health, and chronic conditions.
[b] Logistic regression model including age, gender, socio-professional category, self-perceived health, chronic conditions, anxiety score, and attitudes towards the general environment.
[c] Linear regression model including age, gender, socio-professional category, professional status, current smoking, self-perceived health, and chronic conditions.
[d] Linear regression model including age, gender, socio-professional category, professional status, current smoking, self-perceived health, chronic conditions, anxiety score, and attitudes towards the general environment.
[e] For 0.396 V/m increase.

Table 6
Results of the interaction and sensitivity analyses on the association between RF-EMF exposure from MPBSs and insomnia-like symptoms.

Additional variable	Interaction EMF- Attitudes (N = 340)							
	Model[a]		Model[a] « city »		Model[a] « floor »		Model[a] « visibility »	
	OR[b] (95% CI)	p	OR[b] (95% CI)	p	OR[b] (95% CI)	p	OR[b] (95% CI)	p
EMF exposure from MPBS								
In « slightly concerned » participants	0.84 (0.55; 1.31)	0.45	0.80 (0.51; 1.25)	0.33	0.79 (0.50; 1.24)	0.30	0.87 (0.55; 1.38)	0.56
In « worried » participants	1.80 (1.14; 2.84)	0.01	1.75 (1.10; 2.78)	0.02	1.64 (1.02; 2.61)	0.04	1.81 (1.13; 2.90)	0.01
In « uninformed participants	2.12 (1.05; 4.26)	0.04	2.11 (1.02; 4.38)	0.05	1.97 (0.96; 4.04)	0.07	2.22 (1.10; 4.50)	0.03

[a] Logistic regression model including age, gender, socio-professional category, self-perceived health, chronic conditions, anxiety score, and attitudes towards the general environment.
[b] For 0.396 V/m increase.

Table 7
Results of the stratification and sensitivity analyses on the association between RF-EMF exposure from MPBSs and insomnia-like symptoms.

	Stratification on visibility				Interaction EMF- Attribution		
	Model[a] N = 223 MPBS « not visible »		Model[a] N = 116 MPBS « visible »			Model[b] N = 318	
	OR[c] (95% CI)	p	OR[c] (95% CI)	p		OR[c] (95% CI)	p
EMF exposure from MPBS					**EMF exposure from MPBS**		
In « slightly concerned » participants	0.90 (0.39; 2.10)	0.80	1.02 (0.58; 1.80)	0.94	In participants with no attribution	0.87 (0.46; 1.66)	0.68
In « worried » participants	2.47 (1.21; 5.03)	0.01	1.36 (0.62; 2.98)	0.44	In participants with attribution	2.38 (1.31; 4.34)	0.005
In « uninformed participants	2.28 (0.83; 6.30)	0.11	1.53 (0.51; 4.61)	0.45	In participants who « don't know »	1.05 (0.74; 1.49)	0.80

[a] Logistic regression model including age, gender, self-perceived health, chronic conditions, anxiety score, and attitudes towards the general environment.
[b] Logistic regression model including age, gender, socio-professional category, self-perceived health, chronic conditions, anxiety score, and attribution of symptoms to radiofrequencies.
[c] For 0.396 V/m increase.

There was also a statistically significant positive interaction, when the variable "attitudes towards the general environment" was replaced by the variable "attribution of symptoms to radiofrequencies", between RF-EMF exposure and such attribution. There was a significant association between RF-EMF exposure and insomnia-like symptoms only for participants who attributed their symptoms "moderately", "quite a bit" or "a great deal" to radiofrequencies: OR = 2.38, 95%CI (1.31–4.34). This association was not observed for participants who indicated "no or little attribution" or "don't know".

4. Discussion

The findings of the present study do not support the hypothesis of an association between RF-EMF exposure from MPBSs and health outcomes, such as self-reported non-specific or insomnia-like symptoms in the general population. However, they may suggest a possible association between such exposure and insomnia-like symptoms among people reporting environmental concerns.

4.1. Strengths and limitations

This study is the first to assess exposure of people living in the immediate vicinity of MPBSs in urban areas in France to electromagnetic fields. It is one of the few studies of this issue to have identified a target population residing in buildings located within 250 m of selected MPBSs with at least one dwelling located in the main transmit beam of the antenna. The choice of 250 m was made because the annual listing of the ANFR atypical points, i.e. with a global level >6 V/m, showed that none occurred at a distance from an MPBS of more than 250 m. An Austrian study used a similar approach, selecting the areas affected by each of the

selected MPBSs on the basis of the manufacturers' data (Hutter, 2006). The selection method used in our study, together with a home exposure measurement in each of the apartments, allowed us to include a relatively large number of dwellings with an average exposure >1 V/m (36 of 354, or nearly 10% versus 5% in the Austrian study) and thus obtain a sufficiently large gradient of exposure between the participants. The average exposure to RF-EMF from MPBSs, measured at the maximum exposure point of the dwelling, was 0.43 V/m (0.03–3.58). It is still low, well below the ICNIRP protection limits and in the range of the field strengths found in Europe (Gajsek et al., 2015). Nevertheless, it is higher than that measured in recent epidemiological studies. For example, in the Swiss Qualifex study, the average exposure to RF-EMF from MPBSs and broadcast transmitters was 0.09 V/m (Frei et al., 2012). In the Dutch Emphasis study, the average exposure to RF-EMF from MPBSs was 0.12 V/m (0–1.09) (Balaitsas et al., 2015).

In our study, the home exposure measurements were carried out according to the reference method in France, following a standardized procedure, which consists of determining the exposure at the maximum point of exposure of an apartment of all fields from various frequencies, including those from MPBSs (ANFR, 2017). For the apartments under study, the results show that the share of exposure was predominantly from MPBSs (64%), confirming a posteriori the relevance of the selection method for the study population. As the study focused on the background RF-EMF from MPBSs, exposure from mobile-phone handsets (uplink) was not considered.

One limitation of our study was the estimation of exposure to RF-EMF from MPBSs solely at home, with no information on exposure at the workplace or during transportation, thus leading to a potential misclassification of the participants according to their exposure. It is unlikely that the exposure classification would depend on the health outcomes of the participants. Such non-differential misclassification would have resulted in a negative bias if there was a true association between RF-EMF exposure and health outcomes. A further limitation of this study was that the RF-EMF measurements were only performed once. This could introduce a certain level of exposure misclassification if the spot measurements were not representative of long-term individual exposure. However, a subsample of the study participants was supplied with a personal exposure meter (PEM) for 48 h (n = 152) and, for some, seven days (n = 40) to verify the representativeness of the spot measurements (De Giudici et al., 2020). The results indicate that the spot measurements reflect the typical exposure at home and that study participants spend two-thirds of their time, on average, at home (De Giudici et al., 2020). However, exposure misclassification may have reduced the statistical power to show the association (Coggon, 2006).

The participants in this study were not randomly selected, but selected based on their living in buildings located at a distance of 250 m or less from a MPBS and in the main transmit beam of the antenna to increase the proportion of participants with high RF-EMF exposure. The study population was generally older, included more women, and was more highly educated than the population residing in cities of 200,000 inhabitants and even more so than the general population in France in 2015 (INSEE, 2015). In contrast, the proportion of people with an occupational activity was very similar in both populations. Hence, the distribution of RF-EMF exposure and health scores derived from the study population cannot be considered to be representative of the entire urban population in France, even more so due to the low response rate.

It is very unlikely that a selection bias occurred in our study. Indeed, the study participants were not informed that the subject of the study was health disturbances related to radiofrequencies and MPBSs before completing the questionnaire. Furthermore, this study was not conducted in areas where people have been actively involved in actions against the installation of MPBSs.

This study focused on nonspecific and insomnia-like symptoms that are not necessarily related to a medical condition and are frequent in the general population (Körber et al., 2011). These subjective health indicators could be considered as a weakness of the study. However, standardized questionnaires were used to assess nonspecific and insomnia-like symptoms. Assessment based on Eltiti score symptoms, including the intensity of 57 items, was chosen to increase the sensitivity (Eltiti et al., 2007a), given the possibly large variation of physiological reactions to RF-EMF and the uncertainty of whether a bioelectromagnetic mechanism actually exists. The validation study of the questionnaire gave similar results to previous studies, and the 75th percentile of symptoms score was 33, between the values of the British and Japanese studies of 26 and 45, respectively (Eltiti et al., 2007a; Hojo et al., 2016). The prevalence of insomnia-like symptoms in our study was slightly higher than that in the general French population using the same indicator (Beck et al., 2012). Moreover, the study examined outcomes only once and, therefore, a certain degree of misclassification was possible.

Self-estimated RF-EMF exposure was not assessed in our study. There is evidence from experimental studies that more symptoms are reported in open provocations in which participants are aware of the exposure status than in double-blind experiments (Eltiti et al.;, 2007b; Wallace et al., 2010). Such increases may be due to fear about the negative effects of exposure (nocebo effect). In our study, it is likely that certain participants overestimated their health disorders, but as they did not know their real level of exposure, misclassification is unlikely (Thomas et al., 2008). A recent study found that sharing exposure results with residents lowered their risk perception (Ramirez-Vazquez et al., 2019). However, only certain factors presumably related to exposure perception could be assessed in this study, such as the floor of the building and visibility of the MPBS from the residence.

Previous studies have shown that both anxiety and environmental concerns are predictive factors for self-reported health disorders (Rubin et al., 2008; Witthöft and Rubin, 2013). These personal characteristics were taken into account in our study, but it was not possible to consider the role of other psychologically relevant variables, such as negative affectivity and somatosensory amplification, to keep the questionnaire relatively short (Witthöft and Rubin, 2013). Based on the large potential indicators, it is difficult to compare our population in terms of these characteristics with other populations. Nevertheless, a study among residents living near an industrial site in France found the same mean anxiety score (Daniau et al., 2018). In the study of Eltiti et al. (2007a), 80.3% of the general population declared not being sensitive to RF-EMF, whereas 76.2% declared little or no attribution of their symptoms to RF-EMF or answered "don't know" in our study.

The general limitation of cross-sectional studies is that exposure and outcome are assessed at the same time and it is therefore difficult to draw any conclusions on the temporal relation between cause and effect. The underlying hypothesis tested in this study was that health disturbances are associated with long-term exposure at home.

Finally, we conducted a large number of sensitivity analyses because of the absence of a known biological mechanism in the low-dose range. Additional shortcomings were low study power, especially for the subgroups, and a broad definition of the susceptible subgroups in the absence of established diagnostic criteria.

4.2. Interpretation

The absence of an association between RF-EMF exposure from MPBSs and self-reported non-specific and insomnia-like symptoms in the overall study population observed in our study is globally in accordance with the results of most epidemiological studies investigating the possible association between objective RF-EMF measurements of MPBS exposure and self-reported nonspecific symptoms (Thomas et al., 2008; Berg-Beckdhoff et al., 2009; Heinrich et al., 2011; Mohler et al., 2012; Frei et al., 2012; Balaitsas et al., 2015, 2016; Martens et al., 2017) or self-reported insomnia-like symptoms (Hutter, 2006; Thomas et al., 2008; Balaitsas et al., 2015; Martens et al., 2017). These findings are also consistent with the overall evidence from experimental studies showing no adverse health disturbances from exposure to low-level RF-EMF

(Rubin et al., 2010; ANSES, 2018). However, an Austrian study found positive associations between RF-EMF exposure and headaches, cold hands or feet, and difficulties in concentrating after adjusting for concerns towards antennas (Hutter, 2006). Nevertheless, this study has been criticized, in particular because the authors analyzed a large number of symptoms and significant results could have occurred by chance (Coggon, 2006).

Given the limited evidence for a mechanism explaining possible adverse effects of RF-EMF on health disturbances and that cross-sectional studies cannot establish temporal precedence, the analyses of effect modifications in the present study were exploratory. After adjustment for personal characteristics and anxiety, there were significant interactions between RF-EMF exposure from MPBSs and environmental concerns (for both attitudes towards the general environment and the attribution of self-reported symptoms to RF-EMF) in the model related to insomnia-like symptoms. The modifier role of such personal characteristics, and thus possible interactions, has been mentioned in previous studies (Mohler et al., 2012; Frei et al., 2012; Balaitsas et al., 2015, 2016). A recent Dutch study showed a consistent association between UMTS exposure and various clusters of symptoms for people declaring to be sensitive to RF-EMF from MPBSs (Balaitsas et al., 2016). A previous cross-sectional study of the same group found sporadic significant interactions between exposure and idiopathic environmental intolerance attributed to RF-EMF, controlling for perceived exposure (Balaitsas et al., 2015). However, other authors have not found any interaction between exposure and a self-reported electro-hypersensitive status (Mohler et al., 2012; Frei et al., 2012).

In our study, environmental concerns were notably based on the variable “attitudes towards the general environment” that discriminated between the three groups of participants. A relationship between RF-EMF exposure and insomnia-like symptoms appeared to be present for those who were “worried” about the general environment. This also appeared to be true for those who reported themselves to be “uninformed”, but the results were less stable, with high confidence intervals, due at least in part to the small size of this group.

Visible exposure sources, such as antennas, may have influenced the perception of the participants of their exposure, especially those who had environmental concerns, creating some reporting bias. The risk of insomnia-like symptoms related to exposure for participants with environmental concerns was similar, whether visibility of the MPBS was included in the model or not. Moreover, this risk was even lower when the MPBS was visible than when it was not. Thus, it cannot entirely be excluded that the observed interaction indicates an actual exposure effect in potentially susceptible population subgroups, such as those who reported environmental concerns. These findings should be explored in future studies.

5. Conclusion

This study contributes to the body of evidence suggesting no adverse effect of residential exposure to RF-EMF from MPBSs on the development of self-reported nonspecific or insomnia-like symptoms in the general population. However, given complex temporal relationships between environmental concerns, personality traits such as anxiety, and health, cohort studies are needed to monitor the development of health disturbances and such individual characteristics in relation to RF-EMF exposure from MPBSs.

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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