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Extremely low-frequency magnetic fields (ELF-MF) and radiofrequency: Risk of childhood CNS tumors in a city with elevated ELF-MF exposure

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ABSTRACT

Background: Central nervous system tumors (CNSTs) are the second most common childhood cancer. While their etiology is unclear, exposure to extremely low-frequency magnetic fields (ELF-MF) and radiofrequency (RF) may be associated with increased risk. This study aims to examine the relationship between ELF-MF and RF exposure and CNST risk in Mexico City's pediatric population.
Methods: A case-control study was conducted in Mexico City (2017–2022), to assess ELF-MF and RF exposure in 200 CNST patients and 793 controls under 16 years old. Residential ELF-MF exposure was measured over 24 h, and RF exposure was assessed through the total duration of cell phone calls and electronic device usage (with and without internet). ELF-MF exposure levels below 0.1 μT and the lowest RF exposure quartile (Q1) served as reference groups for adjusted odds ratio (aOR) analyses. Data analysis was performed using R and SPSS software.
Results: Of all participants, 5.1 % had ELF-MF exposure ≥0.3 μT. Elevated ELF-MF exposure (≥0.4 μT) was significantly associated with an increased risk of CNST (aOR (95 % confidence interval) = 2.39 (1.15–5.00). While cell phone use showed no differences between cases and controls, prolonged tablet use (with and without internet) was significantly associated with increased CNST risk (aOR = 2.53 (1.39–4.61), and 3.53 (1.45–8.59), respectively).
Conclusion: A high proportion of children in Mexico City are exposed to ELF-MF levels ≥0.3 μT, exceeding levels reported in other populations. Elevated residential ELF-MF exposure, as well as prolonged tablet use, both with and without internet connectivity, were significantly associated with an increased risk of developing CNST in childhood.

1. Introduction

Central nervous system tumors (CNSTs) are the most common solid neoplasms in Mexican children, ranking second in overall malignancy only after acute leukemias. The "*Central Brain Tumor Registry of the United States*" (CBTRUS) has reported age-adjusted mean annual incidence rates of both malignant and non-malignant brain and other CNSTs in children and adolescents (0–19 years old) in the United States. This rate was 6.21 per 100,000 inhabitants, with higher rates observed in females compared to males (6.33 vs. 6.10 per 100,000), in Caucasians compared to African Americans (6.42 vs. 4.87 per 100,000), and in non-Hispanics compared to Hispanics (6.50 vs. 5.35 per 100,000) (Ostrom et al., 2021). Although few statistical studies have been conducted in Mexico, data from the "*Mexican Social Security Institute*" (IMSS) revealed annual age-adjusted incidence rates in Mexico City between 1996 and 2013. During this period, the average rate was 18.9 per 100,000, with a notably higher incidence among children aged 1–4 years (19.3 per 100,000) (Fajardo-Gutiérrez et al., 2016).

The etiology of CNST remains largely unclear, as summarized in Table 1. Nevertheless, genetic and environmental factors have been implicated, as described by Adel Fahmideh et al. (2021) (Adel Fahmideh and Scheurer, 2021). According to Andersen et al. 2013, genetic factors account for only about 4 % of cases, while environmental factors, such as a history of atopic diseases [odds ratio (OR): 1.03, 95 % confidence interval (95 % CI: 0.70–1.34)], remain controversial. Similarly, Lupastsch et al. 2018 reported comparable findings: pet contact (OR: 0.8; 95 % CI:0.70–1.00), farm visits (OR: 0.6; 95 CI: 0.50–0.80), common infections (OR: 0.9; 95 % CI: 0.70–1.20), and day-care attendance (OR: 0.9; 95 % CI: 0.70–1.20). Wang et al. (2017) also analyzed parental age as a risk factor, reporting an association between advanced maternal age (OR: 3.71; 95 % CI: 1.77–7.76) and the development of pediatric ependymomas and choroid plexus tumors, while paternal age showed no significant association (OR: 0.97; 95 % CI: 0.56–1.69). In contrast, a study by Rios et al. (2018) in a Hispanic population found no association between parental age and the risk of pediatric CNST. Notably, among the environmental risk factors most strongly associated with CNST in childhood are maternal and paternal exposure to pesticides (ORs: 1.40 and 1.26, respectively), as well as birthweight greater than 4000 g. (OR: 1.6) (Table 1).

On the other hand, exposure to ionizing radiation remains the only established risk factor with a proven causal role in the development of CNSTs. However, it accounts for only a small portion of cases (Adel Fahmideh and Scheurer, 2021; McNeill, 2016).

Since Wertheimer and Leeper described a possible association between residential exposure to high levels of electric fields and childhood

Table 1
Possible environmental contributors to the origin of childhood CNST.

Variable	Odds Ratio	(95 % CI)		Reference
		Lower Confidence Interval	Upper Confidence Interval	
Atopic diseases	1.03	0.70	1.34	Andersen et al. (2013)
Pet contact	0.80	0.70	1.00	Lupatsch et al. (2018)
Farm visits	0.60	0.50	0.80	Lupatsch et al. (2018)
Common infections	0.90	0.70	1.20	Lupatsch et al. (2018)
Daycare attendance	0.90	0.70	1.20	Lupatsch et al. (2018)
Maternal age	3.71	1.77	7.76	Wang et al. (2017)
Paternal age	0.97	0.56	1.69	Wang et al. (2017)
Hispanic maternal age	0.88	0.26	2.97	Rios et al. (2018)
Hispanic paternal age	0.99	0.34	2.85	Rios et al. (2018)
Maternal exposure to pesticides[a]	1.40	1.20	1.80	Vidart et al. (2018)
Paternal exposure to pesticides[b]	1.26	1.13	1.40	Van Maele-Fabry et al. (2017)
Birth weight >4000 gr	1.6	1.23	2.09	Dahlhaus et al. (2017)

[a] During pregnancy.
[b] Residential exposure. This information is obtained from: Adel Fahmideh and Scheurer (2021) and McNeill KA (2016).

[1] These authors contributed equally and share first authorship.

cancer (Wertheimer and Leeper, 1979), the association between exposure to high levels of extremely low-frequency electromagnetic fields (ELF-MF) and CNST has been extensively investigated (e.g., Castaño-Vinyals et al., 2022; Kheifets et al., 2010; Mezei et al., 2008; Saito et al., 2010). More recently a potential association between radiofrequency (RF) exposure and development of CNST has also been examined (e.g., Carrubba and Marino, 2008; de Pomerai et al., 2003; Grigor'ev, 2011; Ivancsits et al., 2002; Olsen et al., 1993; Simkó and Mattsson, 2004; Wolf et al., 2005). In 2002, the *International Agency for Research on Cancer (IARC)* classified ELF-MF as "possibly carcinogenic to humans" (Group 2B), primarily based on childhood leukemia epidemiologic studies (IARC, 2002)Expsoure to RF was also later classified as "possibly carcinogenic to humans" or Group 2B(International Agency for Research on Cancer, 2011) (IARC, 2013). Following publication of more recent studies, some argued for reevaluation of RF exposure by IARC (e.g., Morgan et al., 2015; Falcioni et al., 2018; Wyde et al., 2018). In 2024, an Advisory Group to IARC listed RF exposure among "Agents recommended for evaluation by the IARC Monographs with high priority" (González et al., 2024).

Over the past decades, there has been a significant surge in the use of cellular telephones among the general population, with its reach extending to adolescents and children at increasingly younger ages (Böhler and Schüz, 2004). In a study conducted in Korea, it is estimated that up to 90 % of children in elementary schools own a cell phone. Of particular concern is the trend of earlier use among children from lower socioeconomic backgrounds and those with parents of lower educational levels (Byun et al., 2013). Notably, Mexico City boasts 137 subscriptions per 100 inhabitants, making it as the city with the highest number of lines per inhabitant in the country, as reported by the Mexican Federal Telecommunications Institute (Instituto Federal de Telecomunicaciones, 2019)(Instituto Federal de Telecomunicaciones, n.d.). This trend coincides with a slight increase of CNST in pediatric population observed by Fajardo et al. from 2008 to 2013. Unfortunately, there are no subsequent studies in Mexico that could provide further insight into whether this upward trajectory in cellular phone usage continued to coincide with the consistent rise in the incidence of CNS tumors in our population up to the present day (Fajardo-Gutiérrez et al., 2016).

To date, the most extensive studies investigating the association between RF exposure and CNST have primarily focused on the adult population (Coureau et al., 2014; The INTERPHONE Study Group, 2010; Vila et al., 2018). While some studies have included the pediatric population (Aydin et al., 2011; Sadetzki et al., 2014), they are characterized by participation biases and with minimum inclusion ages that do not align with the age at which children are typically exposed to RF for the first time.

Considering the WHO recommendations, it is imperative to conduct separate studies on the pediatric population due to their distinct biological characteristics (e.g., WHO, 2010). Children possess developing central nervous systems, characterized by their ongoing growth and maturation. They also have higher water content and differing ion concentrations (Kheifets et al., 2005), making their brain tissue more conductive compared to that of adults. Additionally, their smaller head circumference enables RF penetration into deeper brain regions. These factors, with variations in proportional exposure levels compared to adults, highlight the imperative for independent research. Therefore, findings from adult studies cannot be extrapolated to the pediatric population.

Given the elevated prevalence of exposure to high levels of ELF-MF in Mexico City, alongside an indeterminate frequency of RF exposure and the notable incidence rates of CNST, our study aimed to explore the potential correlation between ELF-MF and RF exposure and the risk of CNST in the pediatric population of Mexico City (Pérez-Saldivar et al., 2011).

2. Materials and methods

A case-control study was conducted from March 2017 to February 2022, including children under the age of 16 residing in Mexico City. Controls were selected to match cases based on sex, age (±18 months), and the health institution. A frequency-matched approach was followed.

2.1. Cases

All incident cases diagnosed with primary CNST were recruited from six public tertiary-level care hospitals in Mexico City, namely: Hospital de Pediatría "*Dr. Silvestre Frenk Freund*", Centro Médico Nacional (CMN) "*Siglo XXI*", Instituto Mexicano del Seguro Social; Hospital Infantil de México "*Federico Gómez*", Secretaría de Salud (SS); Instituto Nacional de Pediatría, SS; Hospital General "*Dr. Gaudencio González Garza*", CMN "*La Raza*", IMSS; Hospital Juárez de México, SS; and Hospital CMN "*20 de Noviembre*", Instituto de Seguridad Social al Servicio de los Trabajadores del Estado (ISSSTE). All participants were prospectively registered and invited to participate in the study (see Fig. 1). Children with secondary CNSTs (metastases) and those who did not reside in Mexico City were excluded from the analysis.

2.2. Controls

Control participants were selected from second-level hospitals and institutions that referred the cases to the tertiary care center for diagnostic confirmation and specialized treatment, in accordance with institutional referral protocols, as follows: Hospital General Regional "*Dr. Carlos McGregor Sánchez Navarro*", IMSS; Hospital General "*1ro de Octubre*", ISSSTE; Hospital Pediátrico de Moctezuma, SS de la Ciudad de México (SSCDMX); Hospital Pediátrico de Iztapalapa, SSCDMX; Hospital Pediátrico Legaria, SSCDMX; Hospital Pediátrico de Coyoacán, SSCDMX; Hospital Pediátrico "*La Villa*", SSCDMX; Hospital Pediátrico de Azcapotzalco, SSCDMX; Hospital Pediátrico de Tacubaya, SSCDMX. The controls were selected from second-level hospitals instead of first-level clinics based on the assumption that the participation rate may be higher among patients in second-level hospitals.

Mexico's public healthcare system is structured into three levels of care, organized according to both geographic coverage and disease complexity. First-level clinics provide primary care services such as general medical consultations, immunizations, and growth monitoring to local populations, but they do not offer hospitalization. Second-level hospitals manage more complex conditions, including those requiring inpatient care. They also act as referral points for rare or severe conditions, such as central nervous system tumors (CNSTs), to tertiary-level centers for diagnostic confirmation and specialized treatment. In addition, second-level hospitals cover broad geographic areas, which helps reduce the risk of overmatching in environmental exposure variables, particularly those related to ELF-EMF. These exposures are often influenced by residential proximity to high-voltage power lines or substations, and broader geographic recruitment increases heterogeneity in such factors among controls.

The control group comprised children without CNST who received care in various hospital departments, including ambulatory surgery, emergency, pediatrics, ophthalmology, and orthopedic outpatient services. To reduce the risk of introducing selection bias due to overrepresentation of certain conditions among controls, children whose reason for hospital admission was neoplasms, hematological diseases, allergic diseases, acute infections, or congenital malformations/disorders (whether visible or previously diagnosed) were not invited to participate (see Fig. 1). However, to capture relevant medical history, the questionnaire administered to parents included specific questions about the child's past history of allergic diseases and infections, regardless of the reason for their hospital visit.

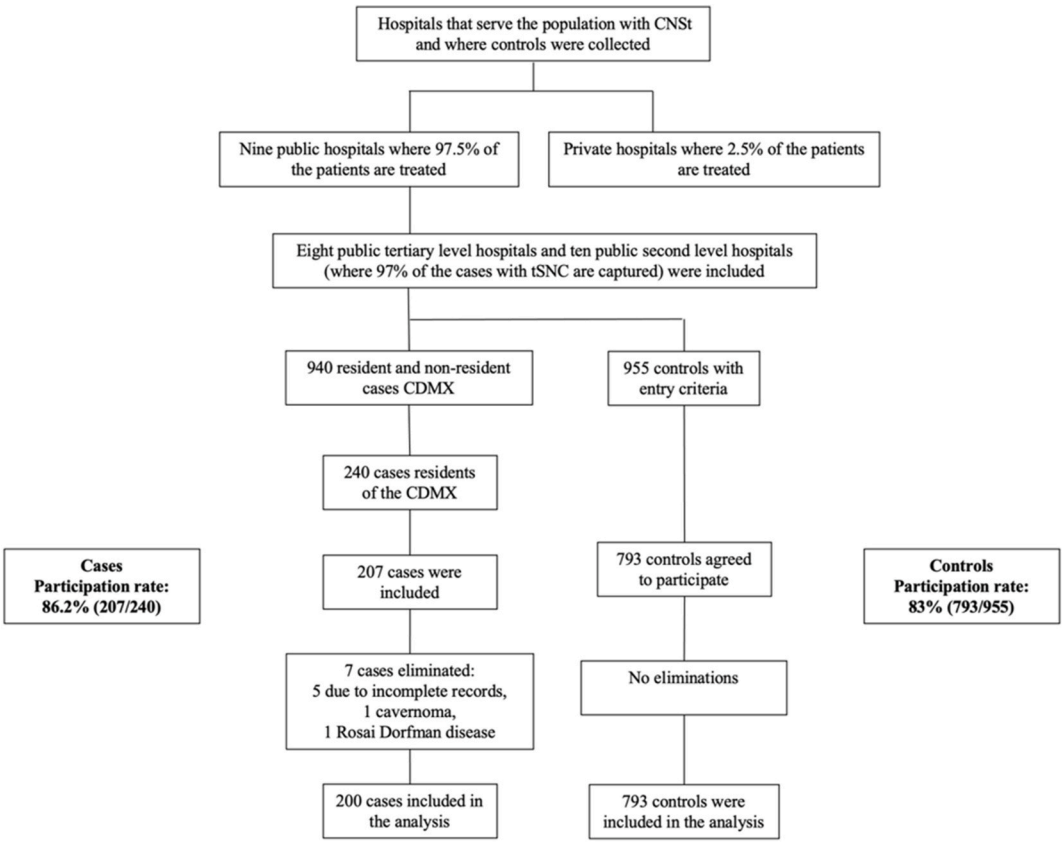

Fig. 1. Diagram of selection on cases and controls, groups and participation rate.
All incident cases diagnosed with primary CNSt in any of the eight public hospitals of Mexico City -Hospital de Pediatría, "Dr. Silvestre Frenk Freund" Centro Médico Nacional (CMN) "Siglo XXI," Instituto Mexicano del Seguro Social (IMSS); Hospital Infantil de México Federico Gómez, Secretaría de Salud (SS); Instituto Nacional de Pediatría, SS; Hospital General "Dr. Gaudencio González Garza," CMN "La Raza," IMSS; Hospital Juárez de México, SS; and Hospital CMN "20 de Noviembre," Instituto de Seguridad Social al Servicio de los Trabajadores del Estado (ISSSTE).
The control participants were selected from the second-level hospitals of the same health institution -Hospital General Regional "Dr. Carlos McGregor Sánchez Navarro," IMSS, Hospital General 1ro de Octubre (ISSSTE); Hospital Pediátrico de Moctezuma, Secretaria de Salud de la Ciudad de México (SSCDMX); Hospital Pediátrico de Iztapalapa, SSCDMX; Hospital Pediátrico Legaria; Hospital Pediátrico de Coyoacán SSCDMX; Hospital Pediátrico La Villa, SSCDMX; Hospital Pediátrico de Atzcapotzalco, SSCDMX; Hospital Pediátrico de Tacubaya, SSCDMX.
A total of 940 incident CNSt patients were registered during the study period. Of these, 240 (25.5 %) had primary CNSt residents of Mexico City, and parents of a total of 207/240 (86.2 %) patients (cases) provided consent for the interview and the 24-h ELF-MF measurement at their place of residence.
Of the 207 cases surveyed, 7 cases were eliminated: 5 cases for having incomplete records of which the information could not be completed because the patients changed their address and could not be located; one case due to its definitive histopathological study resulted on cavernoma (not a tumor) and one case due to its definitive histopathological study resulted on Rosai Dorfman's Disease (not a primary CNS tumor).
A total of 955 potential control participants met the selection criteria and were invited to participate in the present study. Parents of 83.0 % (n = 793) of these potential control participants provided consent for the interview and the 24-h ELF-MF measurement at their place of residence.

2.3. Ethics

The Ethics and National Committee of Scientific Research approved this study (R-2016-785-057). Additionally, approval was obtained from each participating hospital and health institution.

2.4. Study overview

Trained staff were assigned to each hospital to identify incident cases of CNST and recruit participants for the control group. The parents of children were required to sign an informed consent form if they agreed to participate in the interview and permit ELF-MF measurements at their residence and RF exposure estimation. The interview was conducted using the same questionnaire for both cases and controls, which we have utilized in previous epidemiological studies about ELF-MF exposure and leukemia in children (Flores-Lujano et al., 2009; Mejia-Arangure et al., 2007). Additionally, items such as RF, traumatic brain injury (TBI), contact with animals, diabetes and arterial hypertension were included in the questionnaire.

2.5. Magnetic field measurements

ELF-MF exposure was measured using EMDEX II Gaussmeters (Enertech Consultants, Campbell, CA). Trained technicians, blinded to the participants' case or control status, conducted EMF measurements in the household where the child had been living during the year preceding the date of diagnosis (for cases) or the date of the interview (for controls). For the 24-h measurement, the device was placed in the child's bedroom, typically adjacent to the bed, most commonly at the head of the bed or on a nearby surface such as a nightstand. Broadband ELF-MF levels (30–800 Hz) and the vector components (X, Y, Z) were recorded every 4 s throughout the 24-h period. It should be noted that no specific precautions were taken to avoid proximity to electrical appliances (e.g., refrigerators, fans, electrical outlets), and the presence or absence of such appliances near the measurement location was not documented.

The information was collected, transferred, and stored using the EMCALC 2016 software (Enertech Consultants). The geometric mean of the 24-h measurement was employed to classify the ELF-MF exposures based on different intensity levels. A level of exposure at <0.1 μT was

used to define the reference category. Thus, ELF-MF exposure categories were as follows: <0.1, ≥0.1 to <0.2, ≥0.2 to <0.3, ≥0.3 to <0.4, ≥0.4 μT.

Information on exposure to radiofrequency (RF) was obtained through structured face-to-face interviews with the child's mother or guardian using a standardized questionnaire. Data collected included age at first mobile phone use, number of months since first use, total number of days of effective use, cumulative number of calls made, total lifetime duration of calls (in minutes), and number of text messages sent. Additionally, average daily duration of use of mobile phones, electronic tablets, and computers (with and without internet) was recorded. Finally, the total duration of video calls made by the child on any electronic device was also recorded. Once the data for all RF variables were obtained, they were categorized into quartiles (Q1, Q2, Q3, and Q4) based on the range of values.

We designated exposure level Q1 as the reference category for some cell phone-related variables, and 0 as the reference category for all other variables, as the majority of subjects fell within this value. Thus, our exposure categories were defined as follows:

- Duration in months since the child started using cell phone: 0 to 14, 14.1 to 33, 33.1 to 48, >48 months
- Total number of days of effective cell phone use: 0 to 365, 366 to 730, 731 to 1460, >1460 days
- Cumulative number of calls made by the child: 0 to 24, 25 to 152, 153 to 720, >720
- Total duration of phone calls made by the child throughout their lifetime: 0 to 52, 53 to 432, 433 to 2190, >2190 min
- Total number of messages sent by the child: 0, 1 to 728, 729 to 3276, 3277 to 14600, >14600
- Duration of cell phone use with internet: 0, 1 to 21900, 21901 to 65700, 65701 to 218400, >218400 min
- Duration of cell phone use without internet: 0, 1 to 12480, 12481 to 31200, 31201 to 75075, >75075 min
- Duration of e-tablet use with internet: 0, 1 to 10080, 10081 to 43800, 43801 to 127440, >127440 min
- Duration of e-tablet use without internet: 0, 1 to 3120, 3121 to 14414, 14415 to 65700, >65700 min
- Duration of video calls made by the child on any electronic device: 0, 1 to 680, 681 to 5820, 5821 to 21840, >21840 min
- Duration of computer use with internet access: 0, 1 to 7695, 7696 to 19760, 19761 to 56160, >56160 min
- Duration of computer use without internet access: 0, 1 to 4440, 4441 to 6840, 6841 to 37440, >37440 min

Data were collected from 2017 to 2022 and analyzed prospectively. Study variables included the children's sex (male/female), age (<9 years/9 years or older), birth weight (≤3500 g/>3500 g)), low birth weight (≤2500 g/>2500 g), TBI (history of skull fracture, brain contusion, or intracranial hemorrhage, yes/no), living with animals (daily contact with animals, yes/no), atopic diseases (history of atopy or allergic disease, yes/no), family history of cancer (yes/no), infection during the first year of life (yes/no), daycare attendance (yes/no), parental age at conception of the index child (/≤35 years/>35 years), parental education level (<10 years/≥10 years), type of residence (apartment or house), history of radiation exposure, maternal hypertension (yes/no), preeclampsia (yes/no), previous miscarriages (yes/no), maternal diabetes (yes/no), gestational diabetes (yes/no), and maternal obesity before pregnancy (yes/no).

2.6. Statistical analysis

The analysis was conducted using R version 4.1.3, Julia version 1.9.3, and SPSS software (version 25; IBM Statistical Package for the Social Sciences, Chicago, IL). Unadjusted odds ratios (OR), adjusted OR (aOR), and their respective 95 % confidence intervals (CI) were calculated using unconditional logistic regression analysis. Adjustment for multiple significant tests was not performed. Logistic regressions were conducted separately for ELF-MF and RF exposure variables. Initially, we examined the associations between ELF-MF or RF exposure (≥0.1 μT or > Q1 or 0, respectively) and study variables. Subsequently, to identify any potential confounding variables were compared OR obtained before and after adjusting for each variable. None of the potentially confounding variables yielded a difference greater than 10 % between the association to ELF-MF and RF with the risk of developing CNST. Variables associated with either the risk of developing CNST (such as type of residence, paternal education level, and infections during the first year of life) or with exposure to ELF-MFs (≥0.1 μT) or RF (>Q1 or >0) (such as paternal education level, birth weight, and health institution) (data not shown), along with matching variables [child's sex, age (as a continuous variable), and health institution], were incorporated into a logistic regression model. Subsequently, the individual effect of each covariate was assessed until the most parsimonious model was determined. Infections during the first year of life, head trauma, living with animals, atopic diseases, history of radiation exposure, maternal hypertension, preeclampsia, previous miscarriages, maternal type 2 diabetes, and gestational diabetes were excluded from the model due to lack of significant differences in risk estimations when including or excluding these variables. Consequently, the most parsimonious (final) model comprised the following variables: child's sex, age, birth weight, and maternal education. Maternal education was selected as the indicator of socioeconomic status based on recommendations from the Childhood Leukemia and Cancer International Consortium (Talibov et al., 2019).

Furthermore, a logistic regression analysis was conducted using ELF-MF and RF exposure as continuous variables, adjusting for the covariates included in the final model. The resulting adjusted odds ratios (aORs) per unit increase, defined as 0.1 μT intervals for ELF-MF and quartile-based intervals for RF exposure, were reported. Additionally, a logistic regression model was developed that included the child's history of radiation exposure, and another model that further incorporated low birth weight (<2500 g vs. ≥2500 g).

3. Results

During the study period, 940 incident CNST pediatric patients were registered. Among them, 240 (25.5 %) had primary CNST and were residents of Mexico City. Parents of 207/240 (86.2 %) patients (cases) consented to the interview and the 24-h ELF-MF measurement at their residence. Of the 207 cases surveyed, 7 cases were excluded: five cases due to incomplete records caused by changes in address and could not be located; one case due to a definitive histopathological study revealing a cavernoma (not a tumor), and another case due to definitive histopathological study showing Rosai Dorfman's disease (not a primary CNST).

On the other hand, 955 potential control participants met the selection criteria and were invited to participate in the study. Parents of 83 % (n = 793) of these potential control participants provided consent for the interview and the 24-h ELF-MF measurement at their residence (see Fig. 1). No differences were observed in sociodemographic characteristics between controls who agreed to participate and those who did not (see Table 2).

Cases exhibited a higher prevalence of family history of cancer (51 % vs. 32 %), TBI (9 % vs. 4 %), infection during the first year of life (23 % vs. 12 %), daycare attendance (23 % vs. 15 %), contact with animals (73 % vs. 63 %), atopic diseases (27 % vs. 20 %), residing in apartments (66 % vs. 57 %), and maternal obesity (18 % vs. 26) compared to the controls. No significant differences were noted between cases and controls regarding sex, age, birth weight, schooling, parental age, breastfeeding, history of radiation exposure, maternal hypertension, preeclampsia, previous abortions, maternal diabetes, or gestational diabetes (see Table 2). No significant differences in maternal education were found

Table 2
Comparative analysis of sociodemographic and other study variables between cases and controls included in the present research.

Variable	Cases		Controls		OR	95 %CI	p-value*
	N	%	n	%			
Child's sex (male)	108	54.0	443	55.9	0.93	0.68-1.27	0.637
Age at diagnosis (cases) (at interview (controls) (<9 years)	89	44.5	354	44.6	1.00	0.73-1.36	0.971
Birth weight (>3500 gr)	32	16.0	167	21.1	0.72	0.47-1.07	0.110
Birth weight (<2500 gr)	17	8.5	102	12.9	0.63	0.37-1.08	0.09
Family history of cancer (yes)	101	50.5	252	31.8	2.19	1.60-3.00	0.000
Infection during the first year of life (yes)	46	23.0	94	11.9	2.22	1.49-3.28	0.000
Daycare attendance (yes)	46	23.0	122	15.4	1.65	1.11-2.40	0.010
Mother's age at conception of the index child (≥35 years)	13	6.5	76	9.6	0.66	0.34-1.18	0.172
Maternal education level (<10 years)	101	50.5	390	49.2	1.05	0.77-1.44	0.751
Father's age at conception of the index child (≥35 years)	30	15.8	150	19.1	0.75	0.48-1.14	0.186
Paternal educational level (<10 years)	99	49.8	354	45.2	1.20	0.88-1.64	0.252
Type of residence (apartment)	132	66.0	454	57.2	1.44	1.05-2.01	0.025
Traumatic Brain Injury (yes)	18	9.0	35	4.4	2.15	1.16-3.84	0.010
Living with animals (yes)	145	72.5	499	62.9	1.55	1.11-2.20	0.011
Atopy history (yes)	54	27.0	162	20.4	1.44	1.00–2.05	0.044
Nursing	179	89.5	677	85.3	1.45	0.90-2.44	0.130
History of radiation exposure	61	30.5	289	36.4	0.77	0.55-1.07	0.116
Maternal hypertension (yes)	8	4.0	30	3.8	1.08	0.45-2.28	0.886
Maternal preeclampsia (yes)	20	10.0	75	9.5	1.07	0.62-1.77	0.816
Previous miscarriages (yes)	32	16.0	130	16.4	0.98	0.63-1.47	0.893
Maternal type 2 diabetes (yes)	3	1.5	18	2.3	0.68	0.15-2.07	0.499
Maternal gestational diabetes (yes)	1	0.5	17	2.1	0.26	0.01–1.28	0.119
Maternal obesity prior to pregnancy (yes)	36	18.0	204	25.7	0.64	0.42-0.93	0.023

N = 993 Subjects: 200 cases, 793 controls. *Pearson's Chi-square. OR are not adjusted. Categories for each variable considered as exposition. The categories per variable considered as reference are not displayed. CI confidence interval.

between cases and controls (OR = 1.05; 95 % CI: 0.77–1.44).

The association observed with exposure levels ≥0.4 μT remained significant when radiation history was included in the model (OR 2.30, 95 % CI 1.10–4.82), and when both radiation history and low birth weight were included (OR 2.48, 95 % CI 1.19–5.21), as shown in Supplementary Table 1.

The ORs and their 95 % CIs for the four categories of ELF-MF exposure are detailed in Table 3. ELF-MF exposure levels at ≥0.4 μT were associated with an increased risk of CNST (OR: 2.48; 95 % CI: 1.19–5.17). The aOR increased with higher exposure levels; however, significant precision was only observed when the exposure exceeded 0.4 μT, with an aOR of 2.39 (95 % CI: 1.15–5.00) (see Table 3).

When radiation history was included as a control variable, the aOR was 2.30 (95 % CI 1.10–4.82). When birth weight <2500 g was also added, the aOR remained 2.48 (95 % CI 1.19–5.21) (Supplementary Table 1).

For RF exposure, the results of the ORs and 95 % CI for the different categories of phone calls exposure variables are presented in Table 3. No significant associations were observed. In contrast, associations with the risk of CNST for some categories of the variables related with the use of e-tablets with and without internet access were noted. The OR and aOR values for the variable duration of e-tablet use with internet access were statistically significant across almost all of the levels of exposure, except for one category (43801–127440 min). The highest risk of CNST was noted in the high exposure category (aOR: 2.53; 95 % CI: 1.39–4.61) (see Table 3). When radiation history was included as a control variable, the OR was 2.59 (95 % CI 1.42–4.73). When birth weight <2500 g was also added, the OR remained 2.59 (95 % CI 1.42–4.72) (Supplementary Table 1).

These results were similar to those obtained for the categories exposure of the variable duration of e-tablet use without internet access where increased risks were observed in the highest levels of exposure (14415–65700 and > 65700 min), aOR of 4.24 (95 % CI: 1.89–9.51) and aOR of 3.53 (95 % CI: 1.45–8.59), respectively (see Table 3). The OR and aOR for the rest of the RF exposure variables were not associated with an increased risk of CNST. When radiation history was included in the fully adjusted model, the ORs for the exposure categories were 4.50 (95 % CI 2.00–10.12) and 3.58 (95 % CI 1.47–8.76), respectively. When low birth weight was also included, the ORs were 4.08 (95 % CI 1.82–9.17) and 3.43 (95 % CI 1.41–8.36), respectively (Supplementary Table 1).

Logistic regression stratified analysis for ELF-MF and RF was conducted across three age groups (5 years old or less, 6–10 years old, and 11 years old or more). The results are displayed in Tables 4–6.

3.1. Stratified analyses by age groups

Logistic regression analyses stratified for ELF-MF exposure and RF were conducted across three age groups (≤5 years, 6–10 years, and ≥11 years). The results are displayed in Tables 4–6. We observed an association between ELF-MF exposure (≥0.4 μt) and CNST in the age group of 11 years and older (aOR: 5.52; 95 % CI: 1.41–21.67).

For RF exposure, an association between duration (>48 months) since the child started using a cell phone and the risk of CNST was observed in children aged 5 years or younger (aOR: 15.03; 95 % CI: 1.59–142.25). Similarly, more than 1460 days of effective cell phone use were associated with an increase in the risk of developing CNST in pediatric population of that age group (aOR: 10.77; 95 % CI: 1.06–109.31). On the other hand, the duration of use of e-tablets with and without internet was associated with an elevated risk of CNST in the groups aged 6–10 years old and 11 years or older (Tables 5 and 6). The highest risk was observed for the higher category of duration of e-tablet use without internet access (aOR: 6.74; 95 % CI: 1.45–31.27) in the group of 6–10 years of age. Moreover, children aged 6–10 years showed a higher risk of developing CNST associated with prolonged computer use (>56,160 min) with internet access (OR: 5.39; 95 % CI: 1.41–20.66).

4. Discussion

In the present study, the high exposure (≥0.4 μT) to ELF-MF and e-tablet use with and without internet evaluated as a continuous variables were associated with a moderate risk increase of developing CNST. In previous studies, a level of ELF-MF exposure ≥0.3 μT was reported to be

Table 3
Association between exposure to electromagnetic fields (EMF) and radio-frequency (RF) and the risk of developing central nervous system (CNS) tumors: Results of the logistic regression analyses.

Variable	Exposure Category	Total of Patients	OR*	95 % CI	aOR**	95 % CI
ELF-MF (μT)	<0.1 (ref.)	721				
	0.1-0.19	173	1.31	0.88-1.95	1.30	0.87-1.94
	0.2-0.29	48	1.29	0.64-2.60	1.26	0.63-2.54
	0.3-0.39	18	0.54	0.12-2.39	0.56	0.13-2.46
	≥0.4	33	2.48	1.19-5.17	2.39	1.15-5.00
RF: duration in months since the child started using cell phone (months)	0 -14 (ref.)	256				
	14.1–33	243	0.99	0.63-1.54	0.99	0.63-1.56
	33.1–48	316	0.99	0.65-1.51	1.02	0.66-1.58
	>48	178	1.42	0.90-2.26	1.50	0.91-2.46
RF: total number of days of effective cell phone use	0-365 (ref.)	276				
	366–730	236	0.89	0.58-1.37	0.88	0.57-1.37
	731–1460	327	0.83	0.55-1.23	0.83	0.55-1.25
	>1460	154	1.08	0.67-1.74	1.07	0.65-1.78
RF: cumulative number of calls made by the child	0-24 (ref.)	251				
	25–152	248	0.72	0.48-1.10	0.70	0.46-1.06
	153–720	247	0.71	0.47-1.08	0.68	0.44-1.04
	>720	247	0.49	0.31-0.77	0.46	0.29-0.73
RF: total duration of phone calls made by the child throughout their lifetime (minutes)	0-52 (ref.)	253				
	53–432	244	0.74	0.49-1.13	0.72	0.47-1.10
	433–2190	249	0.72	0.48-1-10	0.68	0.44-1.05
	>2190	247	0.54	0.34-0.84	0.51	0.32-0.81
RF: total number of messages sent by the child	0 (ref.)	550				
	1–728	113	0.79	0.47-1.33	0.76	0.45-1.29
	729–3276	109	0.77	0.45-1.32	0.73	0.41-1.28
	3277–14600	113	0.84	0.50-1.40	0.80	0.46-1.40
	>14600	108	0.94	0.57-1.56	0.91	0.52-1.59
RF: duration of cell phone use with internet access (minutes)	0 (ref.)	96				
	1–21900	234	0.40	0.24-0.67	0.40	0.24-0.67
	21901–65700	215	0.26	0.15-0.45	0.26	0.15-0.44
	65701–218400	235	0.23	0.13-0.39	0.21	0.12-0.37
	>218400	213	0.27	0.16-0.47	0.25	0.14-0.44
RF: duration of cell phone use without internet access (minutes)	0 (ref.)	735				
	1–12480	73	0.96	0.52-1.76	0.93	0.50-1.73
	12481–31200	57	1.08	0.56-2.09	1.08	0.55-2.09
	31201–75075	64	0.93	0.48-1.79	0.91	0.47-1.76
	>75075	64	1.35	0.74-2.44	1.36	0.75-2.46
RF: duration of e-tablet use with internet access (minutes)	0 (ref.)	772				
	1–10080	56	2.28	1.26-4.11	2.23	1.24-4.09
	10081–43800	65	2.14	1.22-3.73	2.17	1.24-3.80
	43801–127440	45	1.37	0.66-2.84	1.42	0.68-2.96
	>127440	55	2.54	1.41-4.56	2.53	1.39-4.61
RF: duration of e-tablet use without internet access (minutes)	0 (ref.)	899				
	1–3120	24	2.21	0.93-5.25	2.25	0.94-5.38
	3121–14414	23	1.23	0.45-3.35	1.21	0.44-3.31
	14415–65700	25	4.08	1.83-9.09	4.24	1.89-9.51
	>65700	22	3.06	1.29-7.27	3.53	1.45-8.59
RF: duration of video calls made by the child on any electronic device (minutes)	0 (ref.)	592				
	1–680	100	1.20	0.73-2.00	1.17	0.71-1.92
	681–5820	101	1.18	0.72-1.93	1.13	0.68-1.86
	5821–21840	111	0.40	0.21-0.76	0.35	0.18-0.69
	>21840	89	0.45	0.23-0.90	0.39	0.19-0.80
RF: duration of computer use with internet access (minutes)	0 (ref.)	813				
	1–7695	45	0.88	0.40-1.92	0.87	0.40-1.90
	7696–19760	45	1.01	0.48-2.14	1.08	0.50-2.31
	19761–56160	47	0.96	0.46-2.02	1.02	0.48-2.19
	>56160	43	1.76	0.90-3.44	1.91	0.94-3.88
RF: duration of computer use without internet access (minutes)	0 (ref.)	952				
	1–4440	10	0.44	0.56-3.49	0.43	0.05-3.41
	4441–6840	11	1.48	0.39-5.65	1.53	0.40-5.85
	6841–37440	10	0.44	0.06-3.49	0.42	0.05-3.34
	>37440	10	1.70	0.44-6.62	1.59	0.40-6.33

Abbreviations: ELF-MF = extremely-low-frequency magnetic fields; RF = radiofrequency; OR = odds ratio; aOR = adjusted odds ratio; Ref. = reference category used in the analyses.
*N = 993 Subjects: 200 cases, 793 controls. OR are not adjusted. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.
**N = 993 Subjects: 200 cases, 793 controls. All OR are adjusted for age, sex, weight at birth and maternal education level. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.

associated with the risk of developing childhood CNST (6–9). In the present study, no risk differences were observed when comparing exposure levels of <0.1 μT (as the reference) and those between 0.1 and 0.19 μT, 0.2 to 0.29, and 0.3–0.39 μT.

ELF-MF exposure cutoff points selected in the present investigation were used in previous studies and meta-analyses. For instance, in research conducted by Kheifets L et al. 2010, the authors considered in one analysis the following categories of exposure: 0.1 to <0.2 μT, 0.2 to <0.4 μT, and >0.4 μT with a reference category of <0.1 μT (Kheifets et al., 2010). In other studies conducted by Feychting and Ahlbom (Feychting and Alhbom, 1993) and Preston-Martin et al. (1996), a cutoff point of ≥0.3 μT was established as the highest level of exposure, whereas in the studies by Olsen et al. (1993) and Saito et al. (2010), exposure >0.4 μT was used to designate the highest exposure category. We also used a level >0.4 μT as the highest category of exposure; this

Table 4
Stratified analysis results: Logistic regression examining EMF and RF exposure in relation to CNS tumor risk among children aged 5 Years or younger.

Variable	Exposure Category	n	OR*	95 %CI	aOR**	95 %CI
ELF-MF (μT)	<0.1 (ref.)	200				
	0.1-0.19	40	1.66	0.78-3.55	1.62	0.75-3.51
	0.2-0.29	12	1.29	0.34-4.99	1.37	0.35-5.37
	0.3-0.39	6	0.00	0.00–0.00	0.00	0.00–0.00
	≥0.4	14	2.15	0.69-6.78	2.23	0.70-7.12
RF: duration in months since the child started using cell phone (months)	0 -14 (ref.)	147				
	14.1–33	84	0.95	0.49-1.84	0.96	0.49-1.88
	33.1–48	36	1.25	0.53-2.93	1.26	0.54-2.99
	>48	5	14.97	1.62–138.76	15.03	1.59–142.25
RF: total number of days of effective cell phone use	0-365 (ref.)	147				
	366–730	79	0.84	0.42-1.67	0.85	0.42-1.71
	731–1460	42	1.28	0.58-2.81	1.31	0.58-2.92
	>1460	4	10.78	1.08–107.19	10.77	1.06–109.31
RF: cumulative number of calls made by the child	0-24 (ref.)	109				
	25–152	83	0.68	0.34-1.34	0.65	0.33-1.30
	153–720	45	0.75	0.33-1.71	0.74	0.32-1.72
	>720	35	0.34	0.11-1.04	0.34	0.11-1.08
RF: total duration of phone calls made by the child throughout their lifetime (minutes)	0-52 (ref.)	115				
	53–432	67	0.72	0.35-1.47	0.70	0.33-1.46
	433–2190	70	0.51	0.24-1.09	0.52	0.24-1.14
	>2190	20	0.90	0.30-2.69	0.94	0.31-2.91
RF: total number of messages sent by the child	0 (ref.)	237				
	1–728	20	0.64	0.18-2.28	0.65	0.18-2.31
	729–3276	8	2.19	0.51-9.47	2.22	0.51-9.66
	3277–14600	3	7.29	0.65–82.06	8.50	0.73–98.39
	>14600	4	3.65	0.50-26.53	3.68	0.49-27.43
RF: duration of cell phone use with internet access (minutes)	0 (ref.)	39				
	1–21900	115	0.55	0.25-1.20	0.54	0.25-1.20
	21901–65700	78	0.33	0.13-0.80	0.32	0.13-0.80
	65701–218400	31	0.43	0.14-1.30	0.42	0.14-1.30
	>218400	9	0.51	0.09-2.80	0.549	0.09-2.76
RF: duration of cell phone use without internet access (minutes)	0 (ref.)	203				
	1–12480	30	0.63	0.23-1.73	0.63	0.23-1.73
	12481–31200	23	0.66	0.21-2.04	0.63	0.20-1.97
	31201–75075	12	0.63	0.13-2.97	0.65	0.14-3.11
	>75075	4	1.05	0.11-10.30	0.97	0.10-9.61
RF: duration of e-tablet use with internet access (minutes)	0 (ref.)	231				
	1–10080	19	1.59	0.58-4.39	1.57	0.57-4.35
	10081–43800	13	0.63	0.13-2.91	0.65	0.13-3.07
	43801–127440	4	0.00	0.00–0.00	0.00	0.00–0.00
	>127440	5	0.86	0.94-7.87	0.92	0.10-8.45
RF: duration of e-tablet use without internet access (minutes)	0 (ref.)	255				
	1–3120	7	1.42	0.27-7.52	1.57	0.29-8.42
	3121–14414	6	0.71	0.08-6.21	0.70	0.08-6.07
	14415–65700	2	3.55	0.22–57.72	3.60	0.22–60.33
	>65700	2	3.55	0.22–57.72	4.20	0.25–71.89
RF: duration of video calls made by the child on any electronic device (minutes)	0 (ref.)	210				
	1–680	41	0.84	0.36-1.94	0.86	0.37-1.99
	681–5820	13	2.97	0.95-9.27	3.06	0.97-9.68
	5821–21840	7	0.00	0.00–0.00	0.00	0.00–0.00
	>21840	1	0.00	0.00–0.00	0.00	0.00–0.00
RF: duration of computer use with internet access (minutes)	0 (ref.)	262				
	1–7695	6	0.70	0.81-6.14	0.77	0.09-6.87
	7696–19760	1	0.00	0.00–0.00	0.00	0.00–0.00
	19761–56160	1	0.00	0.00–0.00	0.00	0.00–0.00
	>56160	2	3.52	0.22–57.10	3.32	0.21–54.56
RF: duration of computer use without internet access (minutes)	0 (ref.)	270				
	1–4440	1	0.00	0.00–0.00	0.00	0.00–0.00
	4441–6840	1	0.00	0.00–0.00	0.00	0.00–0.00
	6841–37440	NC	NC	NC	NC	NC
	>37440	NC	NC	NC	NC	NC

Abbreviations: ELF-MF = extremely-low-frequency magnetic fields; RF = radiofrequency; OR = odds ratio; aOR = adjusted odds ratio; Ref. = reference category used in the analyses.
*N = 272 Subjects. OR are not adjusted. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.
**N = 272 Subjects. All OR are adjusted for age, sex, weight at birth and maternal education level. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.

level of exposure was associated with the highest risk increase of CNST development, aOR = 2.48 (1.16–5.09). Moreover, using <0.1 μT as the reference level allows the comparison of our results with other studies that used the same reference exposure category.

In a pooled analysis by Kheifets et al. (2010) Castaño-Vinyals et al. (2022), a level of exposure at ≥0.4 μT was associated with an OR of 1.14 (0.61–2.13) when compared with a level of exposure at <0.1 μT. In another study by Mezei G et al. 2008; Mezei et al. (2008), a higher risk of

Table 5
Stratified analysis results: Logistic regression investigating EMF and RF exposure in relation to CNS tumor risk among children aged 6–10 Years.

Variable	Exposure Category	n	OR*	95 %CI	aOR**	95 %CI
ELF-MF (μT)	<0.1 (ref.)	280				
	0.1-0.19	67	0.96	0.48-1.91	0.94	0.47-1.89
	0.2-0.29	19	2.02	0.74-5.57	1.99	0.72-5.49
	0.3-0.39	6	0.88	0.10-7.67	0.84	0.10-7.36
	≥0.4	10	1.10	0.23-5.31	1.08	0.22-5.26
RF: duration in months since the child started using cell phone (months)	0 -14 (ref.)	70				
	14.1–33	108	0.70	0.32-1.53	0.71	0.32-1.57
	33.1–48	147	0.86	0.42-1.77	0.86	0.42-1.78
	>48	57	1.70	0.75-3.84	1.69	0.75-3.82
RF: total number of days of effective cell phone use	0-365 (ref.)	84				
	366–730	104	0.82	0.40-1.65	0.83	0.41-1.69
	731–1460	148	0.66	0.34-1.30	0.66	0.33-1.30
	>1460	46	0.95	0.40-2.26	0.94	0.40-2.25
RF: cumulative number of calls made by the child	0-24 (ref.)	96				
	25–152	100	0.53	0.26-1.09	0.52	0.25-1.07
	153–720	102	0.87	0.45-1.68	0.84	0.43-1.62
	>720	84	0.45	0.21-0.99	0.43	0.19-0.95
RF: total duration of phone calls made by the child throughout their lifetime (minutes)	0-52 (ref.)	100				
	53–432	110	0.45	0.22-0.91	0.44	0.21-0.89
	433–2190	86	0.70	0.35-1.40	0.67	0.33-1.35
	>2190	86	0.60	0.29-1.23	0.58	0.28-1.20
RF: total number of messages sent by the child	0 (ref.)	231				
	1–728	68	0.64	0.31-1.34	0.63	0.30-1.34
	729–3276	46	0.90	0.41-2.00	0.90	0.40-1.99
	3277–14600	24	0.34	0.08-1.49	0.33	0.07-1.45
	>14600	13	1.11	0.30-4.21	1.07	0.28-4.07
RF: duration of cell phone use with internet access (minutes)	0 (ref.)	36				
	1–21900	88	0.36	0.16-0.84	0.35	0.15-0.80
	21901–65700	104	0.21	0.09-0.50	0.20	0.09-0.48
	65701–218400	107	0.22	0.09-0.51	0.21	0.09-0.49
	>218400	47	0.18	0.06-0.54	0.17	0.06-0.50
RF: duration of cell phone use without internet access (minutes)	0 (ref.)	272				
	1–12480	30	0.67	0.22-1.99	0.64	0.21-1.93
	12481–31200	21	1.73	0.64-4.68	1.80	0.66-4.89
	31201–75075	30	0.67	0.22-1.99	0.69	0.23-2.06
	>75075	29	1.65	0.69-3.93	1.63	0.68-3.90
RF: duration of e-tablet use with internet access (minutes)	0 (ref.)	290				
	1–10080	29	2.02	0.84-4.84	2.00	0.83-4.81
	10081–43800	26	2.35	1.00–5.74	2.46	1.00–6.02
	43801–127440	20	1.77	0.61-5.10	1.73	0.60-5.05
	>127440	17	2.89	1.02–8.21	2.90	1.02–8.28
RF: duration of e-tablet use without internet access (minutes)	0 (ref.)	335				
	1–3120	14	2.77	0.89-8.57	2.27	0.85-8.27
	3121–14414	11	0.50	0.06-3.97	0.51	0.06-4.10
	14415–65700	15	4.36	1.52-12.51	4.62	1.59-13.41
	>65700	7	6.64	1.45-30.50	6.74	1.45-31.27
RF: duration of video calls made by the child on any electronic device (minutes)	0 (ref.)	246				
	1–680	34	1.68	0.75-3.73	1.60	0.71-3.59
	681–5820	44	0.89	0.39-2.04	0.90	0.39-2.07
	5821–21840	37	0.63	0.23-1.70	0.64	0.23-1.72
	>21840	21	0.20	0.26-1.54	0.19	0.03-1.48
RF: duration of computer use with internet access (minutes)	0 (ref.)	324				
	1–7695	25	1.08	0.39-3.00	1.10	0.40-3.07
	7696–19760	16	0.29	0.04-2.22	0.28	0.04-2.15
	19761–56160	8	0.62	0.07-5.10	0.62	0.07-5.12
	>56160	9	5.39	1.41-20.66	5.66	1.43-22.36
RF: duration of computer use without internet access (minutes)	0 (ref.)	365				
	1–4440	7	0.70	0.08-5.93	0.72	0.09-6.12
	4441–6840	6	2.11	0.38-11.74	1.97	0.35-11.04
	6841–37440	4	0.0	0.00–0.00	0.00	0.00–0.00
	>37440	NC	NC	NC	NC	NC

Abbreviations: ELF-MF = extremely-low-frequency magnetic fields; RF = radiofrequency; OR = odds ratio; aOR = adjusted odds ratio; Ref. = reference category used in the analyses.
*N = 382 Subjects. OR are not adjusted. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.
**N = 382 Subjects. All OR are adjusted for age, sex, weight at birth and maternal education level. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.

CNST for exposures ≥0.3 μT was reported OR of 1.68 (0.83–3.43) when compared with exposures <0.1 μT.

In the current study, we identified an association between CNST risk and exposure levels ≥0.4 μT, consistent with previous studies on children conducted by Olsen and Saito. Saito reported an OR of 10.19 (1.05–113) for exposures ≥0.4 μT (Saito et al., 2010), while Olsen reported an OR of 6.02 (0.55–66.4) for a similar exposure level (Olsen et al., 1993).

Table 6
Stratified analysis results: Logistic regression assessing EMF and RF exposure in relation to CNS tumor risk among patients aged 11 Years and older.

Variable	Exposure Category	n	OR*	95 %CI	aOR**	95 %CI
ELF-MF (μT)	<0.1 (ref.)					
	0.1-0.19	241	1.52	0.79-2.92	1.47	0.75-2.85
	0.2-0.29	66	0.63	0.14-2.87	0.62	0.14-2.83
	0.3-0.39	6	0.95	0.11-8.32	1.06	0.12-9.44
	≥0.4	9	5.92	1.52-22.98	5.52	1.41-21.67
RF: duration in months since the child started using cell phone (months)	0 -14 (ref.)	39				
	14.1–33	51	2.99	0.89-10.04	2.92	0.87-9.87
	33.1–48	133	2.03	0.66-6.22	2.14	0.70-6.59
	>48	116	2.28	0.74-7.05	2.22	0.72-6.91
RF: total number of days of effective cell phone use	0-365 (ref.)	45				
	366–730	53	1.21	0.44-3.33	1.16	0.42-3.23
	731–1460	137	1.03	0.43-2.49	1.08	0.45-2.62
	>1460	104	1.24	0.51-3.04	1.20	0.48-2.97
RF: cumulative number of calls made by the child	0-24 (ref.)	46				
	25–152	65	1.22	0.51-2.90	1.26	0.53-3.01
	153–720	100	0.61	0.26-1.44	0.62	0.26-1.48
	>720	128	0.62	0.27-1.42	0.60	0.26-1.40
RF: total duration of phone calls made by the child throughout their lifetime (minutes)	0-52 (ref.)	38				
	53–432	67	1.88	0.71-4.99	2.08	0.77-5.55
	433–2190	93	1.29	0.50-3.35	1.26	0.48-3.30
	>2190	141	0.65	0.25-1.69	0.65	0.25-1.74
RF: total number of messages sent by the child	0 (ref.)	82				
	1–728	25	1.38	0.50-3.82	1.44	0.51-4.05
	729–3276	55	0.52	0.20-1.34	0.49	0.19-1.28
	3277–14600	86	0.88	0.42-1.85	0.84	0.39-1.81
	>14600	91	0.82	0.39-1.71	0.79	0.37-1.70
RF: duration of cell phone use with internet access (minutes)	0 (ref.)	21				
	1–21900	31	0.27	0.80-0.88	0.26	0.08-0.88
	21901–65700	33	0.29	0.09-0.94	0.27	0.08-0.88
	65701–218400	97	0.13	0.05-0.37	0.12	0.04-0.35
	>218400	157	0.20	0.08-0.51	0.20	0.08-0.53
RF: duration of cell phone use without internet access (minutes)	0 (ref.)	260				
	1–12480	13	2.91	0.91-9.29	2.94	0.90-9.56
	12481–31200	13	0.85	0.18-3.95	0.85	0.18-4.00
	31201–75075	22	1.75	0.65-4.70	1.64	0.61-4.45
	>75075	31	1.36	0.55-3.34	1.40	0.57-3.49
RF: duration of e-tablet use with internet access (minutes)	0 (ref.)	251				
	1–10080	8	6.17	1.48-25.82	6.64	1.56-28.31
	10081–43800	26	3.86	1.62-9.18	3.71	1.55-8.88
	43801–127440	21	1.93	0.66-5.60	2.14	0.72-6.35
	>127440	33	3.53	1.59-7.80	3.32	1.49-7.39
RF: duration of e-tablet use without internet access (minutes)	0 (ref.)	309				
	1–3120	3	2.36	0.21–26.51	3.08	0.26–36.96
	3121–14414	6	4.72	0.93-24.03	4.28	0.83-22.06
	14415–65700	8	4.72	1.15–19.47	5.21	1.23-22.00
	>65700	13	2.10	0.62-7.07	2.52	0.72-8.82
RF: duration of video calls made by the child on any electronic device (minutes)	0 (ref.)	136				
	1–680	25	1.21	0.47-3.16	1.16	0.44-3.07
	681–5820	44	1.04	0.47-2.29	1.05	0.47-2.32
	5821–21840	67	0.31	0.12-0.78	0.29	0.11-0.73
	>21840	67	0.48	0.22-1.08	0.47	0.21-1.06
RF: duration of computer use with internet access (minutes)	0 (ref.)	227				
	1–7695	14	0.73	0.16-3.40	0.72	0.15-3.38
	7696–19760	28	1.76	0.73-4.27	1.98	0.80-4.89
	19761–56160	38	1.00	0.41-2.41	1.03	0.42-2.52
	>56160	32	1.23	0.50-3.04	1.26	0.50-3.20
RF: duration of computer use without internet access (minutes)	0 (ref.)	317				
	1–4440	2	0.00	0.00–0.00	0.00	0.00–0.00
	4441–6840	4	1.40	0.14-13.68	2.00	0.20–20.70
	6841–37440	6	0.84	0.10-7.32	0.77	0.09-6.76
	>37440	10	1.80	0.45-7.16	1.53	0.38-6.24

Abbreviations: ELF-MF = extremely-low-frequency magnetic fields; RF = radiofrequency; OR = odds ratio; aOR = adjusted odds ratio; Ref. = reference category used in the analyses.
*N = 339 Subjects. OR are not adjusted. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.
**N = 339 Subjects. All OR are adjusted for age, sex, weight at birth and maternal education level. The categories per variable considered as reference are shown in the first strata per sector and are equivalent to the smallest range. The categories of each variable considered as exposition are the larger strata corresponding to second, third and fourth strata per variable.

We observed a positive association between the risk of developing CNST and higher levels of ELF-MF exposure. No monotonic dose-response relationship was observed in the current study in the adjusted analyses. Similarly, Kheifets et al. found no evidence of a dose-response association in their study.

It has also been reported that levels of ELF-MF exposure above 0.3 μT are relatively infrequent in studies conducted to assess the association between ELF-MF exposure and childhood leukemia (Greenland et al.,

2000). In this context, in a previous study conducted in Mexico City, high proportion of the participating children (14.4 % of cases and 11.3 % of controls) were exposed to levels of ELF-MFs >0.3 μT (Núñez-Enríquez et al., 2020). In this study, we observed that the proportion of the participating children exposed to levels of ELF-MF > 0.3 μT was 7 % (14/200) of cases and 4.6 % (37/793) of controls.

Several factors may explain these observations. First, the study utilized newer-generation gaussmeters (EMDEX II Gaussmeters, Enertech Consultants, Campbell, CA)) which provide higher accuracy in measuring ELF-MF levels. Another possible explanation is that this study was performed 8–10 years after the first one, suggesting potential improvements in the sociodemographic conditions of the population over time. Lastly, the population suffering from leukemia exposed to high levels is larger than the population that develops CNST, which explains why the strength of association is greater and more consistent in the studies reported between ELF-MF and leukemia (Flores-Lujano et al., 2009; Greenland et al., 2000; Mejia-Arangure et al., 2007; Núñez-Enríquez et al., 2020; Pérez-Saldivar et al., 2011) than those observed in ELM-MF and CNSTs (Castaño-Vinyals et al., 2022; Kheifets et al., 2010; Mezei et al., 2008; Saito et al., 2010). However, the frequencies of exposure to ELF-MF in this study are higher than reported in most populations (see Table 7).

In previous studies using measurement methods similar to those used in the current study, low participation rates have been reported (Kheifets et al. cases/controls 40/80 %, Saito et al. cases/controls 76/52 %), which increases the possibility of selection bias (Kheifets et al., 2010; Mezei et al., 2008; Saito et al., 2010). However, the probability of this type of bias was low in our study for the following reasons: (i) six major public hospitals responsible for the treatment of children with CNST from Mexico City (Fajardo-Gutiérrez et al., 2002) participated in our study; (ii) participation rates of both cases (86.2 %) and controls (83.0 %) were high; and (iii) we did not observe differences in sociodemographic characteristics between the controls who agreed to participate and those who did not (see Fig. 1).

The participation rate among controls in this study (83 %) is consistent with that reported in a previous study in Mexico City using hospital-based controls to assess ELF-MF exposure (81.5 %) (Núñez-Enríquez et al., 2020). In contrast, another study that recruited controls from schools reported a substantially lower rate (56 %) (Mejia-Arangure et al., 2007). These differences suggest that higher participation may be facilitated when families are recruited through hospitals, where they receive prior information and reassurance about the home visit and study procedures, potentially enhancing trust and cooperation.

For RF, the largest studies conducted so far are the INTERPHONE (The INTERPHONE Study Group, 2010), CERENAT (Coureau et al., 2014), INTEROCC (Vila et al., 2018), MOBI KIDS (Sadetzki et al., 2014) and CEFALO (Aydin et al., 2011) studies. None of them found an increased risk of RF exposure and the development of CNST at low exposure levels; the INTERPHONE study obtained in the 10th decile of recalled cumulative call time, >1640 h, the OR was 1.40 (1.03–1.89) for glioma, and 1.15 (0.81–1.62) for meningioma; but values of use of this group was reported implausible values (The INTERPHONE Study Group, 2010); in the INTEROCC study (Vila et al., 2018), the largest aOR were obtained for cumulative exposure to RF in the highest exposed category (≥90th percentile) for both gliomas, OR = 1.62 (0.86–3.01) and meningioma OR = 1.52 (0.65–3.55); in the CERENAT study, they only found a statistically significant risk association in the most frequent users when considering cumulative lifetime duration ≥896 h, for gliomas an OR = 2.89 (1.41–5.93) and for meningiomas an OR = 2.57 (1.02–6. 44) and higher number of calls (≥18,360 calls) for gliomas an OR = 2.10 (1.03–4.31) (Coureau et al., 2014); although we should mention that these three were performed with adult population, then the results of the studies cannot be applied to the pediatric population.

The largest reported study including pediatric population is the CEFALO study, in which regular cell phone users did not have a statistically significant increase in probability of having been diagnosed with CNST OR = 1.36 (0.92–2.02) (Aydin et al., 2011). However, in a subgroup of subjects where it was possible to obtain the information from the telephone company, they found an OR of 2.15 (1.07–4.29) when the time of cell phone use was greater than 2.8 years; which may be due to recall bias, typical of this type of study. We did not find a statistically significant positive association for any risk category, in any of the exposure variables with cell phone use (length of time in months, total accumulated days of effective cell phone use, total accumulated number of calls, total accumulated minutes of phone calls), so our results are

Table 7
Proportion of children exposed to extremely low-frequency magnetic fields (ELF-MFs) >0.3 μT in studies conducted in other populations.

Author	Year	Population	Cases (*n*)	≥0.3 μT (%)	Controls (*n*)	≥0.3 μT (%)	ELF-MF measurement
Tomenius	1986	Switzerland	153	3 (1.96)	153	9 (5.88)	Calculated field studies
Savitz et al.	1988	USA	36	3 (8.33)	36	5 (13.89)	Direct measurement
Myers et al.	1990	UK	374	0 (0)	588	0 (0)	Calculated field studies
London et al.	1991	UK	162	17 (10.49)	162	10 (6.17)	Calculated field studies
Verkasalo et al.	1993	Finland	32	1 (3.13)	32	5 (15.63)	Calculated field studies
Olsen et al.	1993	Denmark	833	3 (0.36)	833	3 (0.36)	Calculated field studies
Feychting et al.	1993	Switzerland	38	6 (15.79)	38	22 (57.89)	Direct measurement
Coghill et al.	1996	England	56	1 (1.79)	56	0 (0)	Direct measurement
Michaelis et al.	1997	Germany	176	6 (3.41)	176	6 (3.41)	Direct measurement
Linet et al.	1997	USA	638	42 (6.58)	638	28 (4.39)	Calculated field studies
UK childhood cancer Study Investigator	1999	UK	3838	10 (0.26)	7629	6 (0.08)	Calculated field studies
McBride et al.	1999	Canada	297	14 (4.71)	297	11 (3.7)	Direct measurement
Dockerty et al.	1999	New Zeeland	87	3 (3.45)	87	0 (0)	Direct measurement
Bianchi et al.	2000	Italy	119	0 (0)	476	1 (0.21)	Calculated field studies
Schüz et al.	2001	Germany	514	4 (0.78)	1301	3 (0.23)	Direct measurement
Kabuto et al.	2006	Japan	312	11 (3.53)	603	13 (2.16)	Direct measurement
Wünsch (reported in Swanson et al.)[a]	2009	Brazil	162	11 (6.79)	565	30 (5.31)	Direct measurement
Malagoli et al.	2010	Italy	46	1 (2.17)	184	2 (1.09)	Calculated field studies
Kroll et al.	2010	UK	9665	2 (0.02)	9677	2 (0.02)	Calculated field studies
Wünsch-Filho et al.	2011	Brazil	162	17 (10.49)	565	77 (13.63)	Direct measurement
Does et al.	2011	USA	245	3 (1.22)	269	6 (2.23)	Direct measurement
Jirik et al.	2012	Czech Republic	82	19 (21.95)	81	21 (25.93)	Calculated field studies
Ba Hakim et al.	2014	Malaysia	108	11 (10.19)	118	10 (8.47)	Direct measurement
Salvan et al.	2015	Italy	412	15 (3.64)	587	24 (4.09)	Direct measurement
Nuñez-Enriquez, JC et al.	2020	Mexico	290	42 (14.4)	407	46 (11.3)	Direct measurement
Current study	2023	Mexico	200	14 (7.0)	793	37 (4.6)	Direct measurement

Note: Bold numbers represent the higher frequencies of exposure to levels of ELF-MFs >0.3 μT in studies conducted in different populations. [a]Not published.

consistent with previous studies against a causal relationship of cell phone use with the development of CNST.

The CEFALO study had a minimum inclusion age of 7 years, which does not correspond to the age at which children begin their exposure to RF at present (Böhler and Schüz, 2004), due to we included children older than 1 year, given that from that age the child is exposed to RF, through the cell phone or other electronic screens as a means of entertainment or amusement for children. On the other hand, the participation rate of the controls in the CEFALO study was 71 %, which may weaken its results due to possible measurement and participation biases (Aydin et al., 2011). By obtaining a participation rate of more than 80 % in our cases and controls, we reduced the possibility of this error in the results obtained.

Stratified analysis for ELF-MF or RFexposure was performed to determine whether associations varied across different age groups. This analysis is particularly relevant because younger children spend more time at home and may potentially have a higher exposure to ELF-MF than older children. We did observe ELF-MF exposure with OR of risk statistically significative, only in the group of 11 years old or more, as follows: OR 5.92 (1.52–22.98) and aOR 5.52 (1.41–21.67).

Regarding RF exposure, the use of e-tablets, both with and without internet, was associated with an increased risk of CNST, specifically among children aged 6–10 and those 11 years and older. This age-specific association may reflect different usage behaviors across age groups. In particular, it has been previously reported that younger children spend more time using tablets and laptops, while adolescents tend to use mobile phones more frequently. This pattern, also observed by Birks et al. (2021) and Davis et al. (2023), suggests that younger children may accumulate higher whole-body RF doses from tablet use, which could partly explain the associations found in our study. On the other hand, the observation of OR and aOR statistically significant, in the highest exposure level of the exposure time and cumulative time in 5 years old or less group and computer usage with internet in 6–10 years old group was not consistent in other groups, was present only in one category and in different groups, which could be related with a random statistical causality due to small sample size. The same can be mentioned for aOR statistically significative as protective factor in cell phone usage without internet in 5 years old or less group, observed in the highest category of exposure in this group.

The only statistically significant finding for RF in our study was obtained in the use of the e-tablet with and without internet, with consistently high aORs for the different exposure categories, although we did not observe a dose-response gradient; this finding will have to be confirmed in future research. We did not observe any risk association in the rest of the RF exposure variables studied, such as: messages sent, cumulative time of cell phone use using and not using the internet, cumulative time of computer use using and not using the internet, cumulative time making video calls by the child on any electronic device.

Although an explanation for our results remains unclear, we make the following considerations based on our data: the study was conducted from March 2017 to February 2022, hence, most of it took place during the global pandemic of COVID-19. These circumstances brought important changes in life and in social and educational structure for most countries, including Mexico; especially in our environment, children stopped having face-to-face classes and these were resumed after months of inactivity at a distance via the internet through electronic media, and considering that the e-tablet has a lower cost than computers, it was possibly easier for most children to receive classes with this electronic device, coupled with its versatility and the confinement they lived for almost 2 years, which made the exposure time to the e-tablet was greater compared to other devices and compared to that observed at other times and as reported in previous studies. On the other hand, our findings align with growing evidence that even low-power wireless devices such as tablets can result in meaningful radio-frequency exposure, particularly in children. Advanced anatomical modeling has demonstrated that children absorb significantly more RF radiation than adults due to differences in head size, skull thickness, tissue composition, and proximity of the device to critical structures (Wiart et al., 2008). According to the IARC, RF energy absorption can be twice as high in the brain and up to 10 times higher in the skull bone marrow in children compared to adults (IARC, 2013)(IARC Monograph, 2013). Simulations by Ferreira and de Salles (2015) confirmed that Wi-Fi radiation from tablets held at a typical distance (150 mm) results in significantly higher peak spatial specific absorption rate values in child models than in adult models, particularly in the frontal cortex, eyes, and skull. Furthermore, Birks et al. (2021) showed that tablet use was a major contributor to whole-body RF dose in European children and adolescents, exceeding that from mobile phones in some cases. These findings support the inclusion of tablet use as a non-negligible source of RF exposure, especially when considering cumulative, chronic exposure patterns in children, and highlight the importance of updating safety standards to reflect pediatric vulnerabilities (Davis et al., 2023).

5. Study limitations

The 24-h ELF-MF measurements were performed in the children's bedrooms using a gaussmeter, which has been recommended as one of the best ways to assess ELF-MF exposure (Belyaev et al., 2016). This argument is supported by studies in which a significant correlation between personal geometric mean exposure and bedroom measurements (24-h) has been reported. In these studies, no notable differences were observed between both measurements (personal mean exposure and bedroom measurement), and the reproducibility of results was high (Liorni et al., 2016). However, we did not analyze the influence of external sources, such as high-tension wires, which supplied electricity to the patient's house, which is one of the study's limitations. The distribution of these wires and their proximity to the patient's home are variables of concern in this regard.

A 24-h measurement is a short-term assessment and may be inadequate to evaluate the effects of long-term ELF-MF exposure. For selecting a reference category, we use the use of a level of <0.1 μT to enable comparison with other studies that have also used this threshold as their reference exposure level. However, there is no biological basis for recommending an exposure level of <0.1 μT as the unique reference value.

On the other hand, one limitation of our ELF-MF exposure assessment is the absence of documentation regarding the proximity of electrical appliances to the measurement site within the child's bedroom. Although no specific measures were implemented to exclude such proximity, the placement of the device in the child's usual sleeping area aims to capture relevant exposure conditions. Despite this limitation, it is important to highlight that this study represents the third independent investigation in Mexico reporting an association between elevated residential ELF-MF exposure and an increased risk of childhood acute lymphoblastic leukemia (ALL). These findings are consistent with previous studies conducted in Mexico City, as well as with the seminal work by Linet et al. (1997) in the United States. The reproducibility of these results across diverse populations reinforces the robustness of the association observed.

In regard to the recruitment of controls from second-level hospitals, the following two points were considered: (i) being admitted to a hospital is not associated with exposure to ELF-MF, or RF, and (ii) it is economically more feasible to recruit from second-level hospitals compared to recruiting from the general population. Although selecting controls from first-level clinics might have allowed for a population more comparable to the source population of cases, it posed both logistical and methodological challenges. First-level clinics typically serve smaller and more localized catchment areas. Since exposure to ELF-MF is strongly influenced by residential proximity to power lines and the configuration of local electrical infrastructure, selecting controls from same small geographic areas could have resulted in overmatching on environmental exposures, potentially masking associations of

interest (Dovan et al., 1993). In contrast, second-level hospitals draw patients from wider geographic regions, which reduces this risk of environmental overmatching. Furthermore, recruiting healthy children at the first-level is more complex and often results in lower participation rates, introducing a different form of selection bias. Second-level hospitals not only improve participation feasibility but also share the same referral network as the cases, reinforcing the validity of this control group.

Importantly, in Mexico's public healthcare system, referrals from primary to secondary care are determined strictly by clinical need, not by SES (Gómez-Dantés et al., 2024; Ochoa et al., 2024). Institutions such as the Mexican Institute of Social Security (IMSS), the Institute for Social Security and Services for State Workers (ISSSTE), and the Mexico City Ministry of Health (SSCDMX) provide care that is free or nearly free at all levels. While socioeconomic evaluations may determine cost-recovery fees, no patient is denied care due to financial limitations (Gómez-Dantés et al., 2024; Ochoa et al., 2024). This structure significantly minimizes the risk of SES-related bias in the referral and recruitment processes.

Maternal education, as recommended by CLIC, was used in this study as a proxy for family socioeconomic status (Talibov et al., 2019). We analyzed the association between maternal education and the various exposures, stratified by case-control status, and found no significant differences. These findings suggest that socioeconomic status did not influence exposure levels among cases and controls in this study.

Another limitation of this study is that no stratified analysis was performed to explore whether associations differed among tumor types to know if malignant or benign tumors have different risk rates. Supplementary Table 2 lists the subtypes observed; however, due to the limited number of cases in each category, it was not possible to analyze them individually.

Compared to the control group, head trauma, atopic disease, and living with animals, infections in the first year of living were more frequent in the cases group. This is consistent with previous studies reporting a higher frequency of exposure in the cases vs. controls, indicating a possible causal role. While this warrants future investigation, it was not the primary focus of the present study. On the other hand, obesity, and apartment housing were more frequent in the control group, which may be explained by selection bias or simply because they do not have a causal factor and it is a random exposure (Andersen et al., 2013; Christensen et al., 2012; Shu et al., 2014; Yeni-Komshian and Holly, 2000).

Moreover, to avoid possible confounding biases, some of the other variables that may confound the association between EMF and CNST were included in the study, such as birth weight, schooling, parental age, breastfeeding, radiation history, maternal hypertension, preeclampsia, previous abortions, maternal diabetes, gestational diabetes. No significant differences were observed between groups of these variables.

Nevertheless, an evident mechanism through which exposure to EMF or RF may be associated with CNST has not been established. Therefore, it is possible that other factors related to ELF-MF exposure, which we could not identify in the present study, may be more relevant as risk factors for childhood CNST development.

Another question that deserves discussion is whether the measurement of RF exposure was correct or not, unlike the EMF for which we previously commented that we used a continuous 24-h measurement with a gaussmeter, which although it does not measure all the exposure that the subjects may have had, it is a reliable measurement tool and accepted as the most accurate so far (Belyaev et al., 2016); for RF, in its ordinary use (clinical and/or epidemiological) and due to the variability of use between subjects, a dosimeter cannot be used, since this type of instrument measures the exposure of a tissue for controlled, fixed and potentially known conditions, such as: 1). Tissue absorption properties (water), which vary with the age of the subjects; 2). Tissue size (thickness), which varies with the weight of the subjects; 3). Anatomical variation of tissues (skin, bone, muscle, brain), characteristic of individuals and races; 4). Intensity (self-regulating power of the devices), which varies between brands and models of telephones; 5). Frequency and power of RF, which depend on the places where calls are made, the degree of urbanization, number of antennas, distance between and with them, etc; 6). External devices, such as hats, scarves, or clothing to cover the head and the same cases, lenses, covers or casings to protect cell phones that potentially establish a barrier between the phone and the caller's head; 7). Mode of cell phone use, such as the use of hands-free, speakerphone, etc. that substantially modify the amount of exposure by avoiding direct contact; 8). Time and duration of exposure (Belyaev et al., 2016; Hansson Mild et al., 2005; Rothman et al., 1996).

In relation to exposure time, it has been documented the poor usefulness of the data records of the cellular companies given that the time of minutes of call of a telephone, are not those made by the child, etc., so in relation to this point it has been considered that an interrogation to the minor's parent or the child himself is the best source of estimation to the exposure to radiofrequency, besides that with the use of records of the cellular company you cannot know the laterality of the use of the child's telephone (Rothman et al., 1996). In Massachusetts, USA, a survey of more than 5000 telephone users was conducted to evaluate the usefulness of determining telephone usage information and the type of telephone company records. The information from 3949 respondents was compared with the corresponding data in the company's billing records. It was found that 48 % of account holders were unique users and 69 % were the primary user, i.e., they accounted for at least 75 % of their cell phone usage. The information obtained from the amount of phone usage is highly correlated with the billing record data ($r = 0.74$). It also correlated with the manufacturer's data ($r = 0.92$). Also asked about usage patterns, most reported preferentially using one side of the head when using the phone, but the side of the head used was not strongly associated with manual laterality (Funch et al., 1996). And the opposite can be said, in the estimation of text messages sent, for which it is recommended to consult the cell phone receipt (Gold et al., 2015), we did not find a risk association in the messages sent and a possible explanation is a bias in its measurement, which for the above mentioned was not the best form of measurement or simply because such a relationship does not exist.

Unfortunately, there is no validated questionnaire and possibly it will not be available. The items we considered are the items considered in most studies similar to ours, thus our data can be compared and extrapolated (Aydin et al., 2011; Coureau et al., 2014; Sadetzki et al., 2014; The INTERPHONE Study Group, 2010; Vila et al., 2018). Therefore, prior to implementing our questionnaire to the study subjects, we agreed on it with national experts in the field (Department of Physics of the National Polytechnic Institute and the National Autonomous University of Mexico, and international experts (authors of some of the existing meta-analyses) (e.g., Mezei et al., 2008). In this regard, Berg *et al.* consider that the number of calls alone is a sufficient parameter to estimate the potential cumulative radiation emitted by a cell phone handset (Berg et al., 2005). Our study is exposed to recall and/or explorer biases and of course measurement biases, which even if present, we consider our results to be valid and justify future evaluations.

While recall bias, particularly differential recall between cases and controls, cannot be entirely excluded given that parents were aware of their child's diagnosis, several observations reduce the likelihood that this bias significantly affected the results. First, no association was found between reported use of mobile phones or computers and CNS tumor risk, which would be expected if systematic overreporting by case parents had occurred. Second, the association with tablet use was not observed in all age groups; among children under 5 years of age, no significant association was detected. These findings suggest that the observed association is unlikely to be solely due to recall bias.

The same can be said in relation to our risk category, there is no accepted consensus to determine a cut-off point (Hardell and Sage, 2008), so several researchers have used different elements to compare

and analyze their own data (Aydin et al., 2011; Coureau et al., 2014; Sadetzki et al., 2014; The INTERPHONE Study Group, 2010; Vila et al., 2018), based on epidemiological studies, empirical observations and relevant measurements in clinical practice (Belyaev et al., 2016).

6. Conclusions

In our study population, exposure to elevated ELF-MF was moderately associated with risk of developing CNST among children in Mexico City. The utilization of e-tablets, both with and without internet access, was significantly associated with an increased risk of CNST. Our findings revealed that 3.3 % of our sample, representative of Mexico City, exhibited ELF-MF exceeding 0.4 μT, while 5.1 % surpassed a level >0.3 μT. Considering the ubiquity of electromagnetic field sources in urban environments, our results underscore the importance of informing Mexican governmental and public health authorities about the elevated ELF-MF and RF exposure levels for the implementation of necessary interventions and policies aimed at reducing early-life exposures.

CRediT authorship contribution statement

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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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2025.122858.

Data availability

Data will be made available on request.

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Erratum

Erratum to "Extremely low-frequency magnetic fields (ELF-MF) and radiofrequency: Risk of childhood CNS tumors in a city with elevated ELF-MF exposure" [Environ. Res. Volume 286, Part 2, 1 December 2025, 122858]

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