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Universidad del País Vasco
Euskal Herriko Unibertsitatea

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Erradiazio ez-ionizatzaileko eremu elektromagnetikoekiko esposizioaren ezaugarritzea haurrengan

Mara Gallastegi Bilbao
Doctoral Thesis

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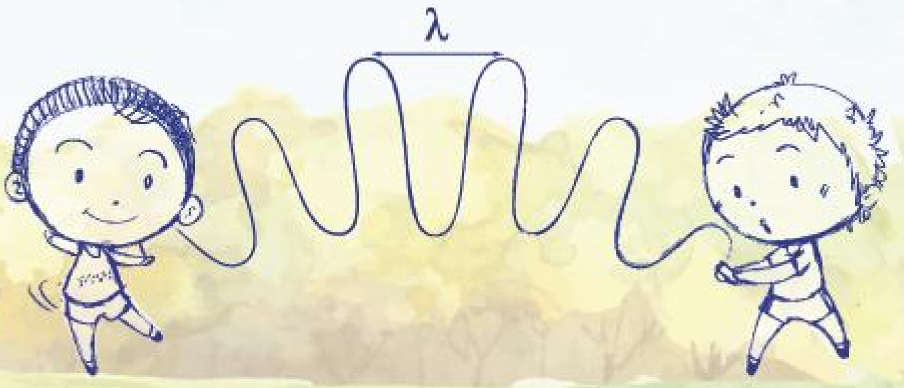

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Ingurumen epidemiologia eta
haurren garapena departamentua

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Characterization of children's exposure to non-ionizing electromagnetic fields

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Report to complete for the European PhD degree

Mara Gallastegi Bilbao

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ESKER ONAK

Doktoretza tesia egitearen prozesua tesi honetan deskribatzen diren uhinen antzekoa izan da, gorabeherek, pozak eta estresak lekua izan dute eta. Gora-behera horien maiztasuna jaisten eta anplitudea txikiagoa izaten lagundu dute askok eta askok.

Gure INMA kohortea osatzen duten familiei zuzenduta dago nire eta gure lehen esker nagusia. Zuen borondatezko partaidetza ezinbestekoa izan da tesi hau burutzeko. Erreza da esaten hiritarren parte-hartzea sustatu behar dela zientzian, baina zuek egin egin duzue. Mila esker zuen etxeen barren barreneko txokoetara sartzen uzteagatik eta kanpo-lana eramangarriagoa egiten lagundu izanagatik. Halaber, mila esker eskoletako irakasle eta zuzendariei eta partaide diren herrietako udalei gure lana errazteagatik.

Ana eta Juanjo, eskerrik asko zuen zuzendari lanagatik. Zuzentzeaz gain, nigan izan duzuen konfiantzak lana aurrera eramaten lagundu dit. Alde akademikoa alde batera utzita, tesi bat egiteak, bere ezaugarriak direla eta, berarekin dakarren karga pertsonala arintzen lagundu didazuelako, eskerrik asko; beti irribarre batekin, umore onez eta lasaitasuna transmitituz. Ana, nik bezain beste sufritu duzu tesi hau. Mila esker nirekin emandako ordu guztiengatik. Zerotik hasi ginen proiektu honetan eta ikasketa-prozesu hau batera egitea oso atsegina eta emankorra izan da.

Esker bereziak proiektu hau posible egin duzuen Loreto eta Jesusi. Zuen lana eginda etxera garaiz joan beharrean, saltsa honetan sartzea erabaki zenutelako! INMA-Gipuzkoako gurasoak zarete. Plazer bat izan da zuek hasitakoan kontribuzio txiki bat egitea. Loreto, gracias por tener cuatro brazos y tener la puerta siempre abierta.

Halaber, eskerrik asko INMA-Gipuzkoa osatzen duzuen ikertzaile guztiei, lana politagoa eta aberasgarriagoa izan dadin egin duzue. Aitana, mila esker proiektu honi buruz hitz egiteagatik eta tesia bertan egiteko aukera ematen lehena izateagatik. Nerea, Ainara, Aritz, Mikel B., Mikel A., Loli, Begotxu, Pilar, Haizea, Eva, Flor, Bidatz, Amaia Irazabal, Ibon, Alain, Ane, Madalen, Asier, Amaia Molinuevo, Amaia Irizar, Maria, Nerea Urbieta, Izaro… denei mila esker!

Hasiera batean lankide izan zineten Nerea Etxezarreta, Ibon eta Saioari, zuek ere bizi izan zenuten tesi hau!

Alaini bidaian eman genituen ordu guztiengatik eta kanpo lanean eduki genituen abentura guztiengatik.

Azkenaldian bulego-kide izan zareten Asier eta Amaiari, desesperazio artean egin ditugun barreengatik, eta Amaiari, estatistika entretenigarri egiteagatik.

A todos los que formáis parte de este gran estudio, en cualquiera de las cohortes y especialmente: a Mònica, con la que ha sido un placer trabajar y por haberme ayudado en todo lo que has podido; a Marieta e Irene, por atreveros a ser las pioneras en investigación de CEM; to Laura, because sharing a similar thesis subject has been nice; a Núria, porque fue estupendo empezar el trabajo de campo con tu apoyo; a Jordi Sunyer, por haber tenido la -que seguro en ese momento denominada- loca idea de embarcarte en este proyecto.

My research visit in Utrecht allowed me to stay in the crest of a wave. Many thanks Anke for accepting me in IRAS and being like my promoter. Thanks a lot for the weekly meetings, for the patience and for receiving me always with a smile. Further, thanks for giving me the opportunity to meet such a nice people. My special thanks to my great office mates, Astrid, Gijs and Luuk. Also to the complete team of IRAS. Bedankt!

A Julián González, por acceder a formar parte de este proyecto y por darme la oportunidad de acercarme a la física de parte de uno de los grandes investigadores del momento. A los investigadores del departamento de ingeniería de comunicaciones, por haberme acogido y recibido con los brazos abiertos para explicarme y discutir con paciencia cualquier problema técnico, sobre todo a Marta y a David.

Gipuzkoako osasun publikoko zuzendariordetzako, Groseko, langileei eta bazkal orduak atseginagoak egin dituzuen guztiei. Pili, Divina, Reme, mila esker iluntzero grosen itxita gera nendin ekidin izanagatik. Mila esker azken momentuan lagundu nauten La Tesis inprentakoei, batez ere Itsasori, eta lagundu nauten EHUko idazkariei.

Ikerketan ondo jarduteko, eta kontuan izanda tesi bat egiteak bakarkako lan asko egitea suposatzen duela, ezinbestekoa da alde pertsonalean ekarpen positiboa egiten duten pertsonak inguruan edukitzea, eta horretan askok lagundu dute.
Algortako lagunak, koadrilakoak eta koadrilatik kanpokoak. Esker bereziak batez ere nire lau urte hauek (eta aurreko guztiak) zuenak egin dituzuenei, benetan egin nezakeela uste zenuten horiei, behar izan denean etxetik ateratzeko aitzakia onenak eduki edo asmatu dituzuenei edota nirekin liburutegian ordu luzeak eman dituzuenei; Garazi, Irene, Naiara, Nerea, Amaia Arti, Ane Remen, Ane Gurtu, Bego, Itsaso, Naia, Teresa, Itziar, Adri…

Donostin pisukide izan zareten guztiei, Andrea eta Laura (kiitos) eta Begoña, Olatz eta Ander, zuen eromenak nire estres momentuak alaitu dituelako!
Ane Zat eta Nereri, zoragarria delako beste hiri batean etxekoak dituzula pentsatzea eta Donostiartze arriskua elkarrekin ekiditea.
Karrerako eta masterreko ikaskide eta lagun guztiei, abentura hau batera hasi genuelako.
Ainara eta Oierri, kanpoan partekatu genuen esperientzia apartagatik.
Oierri, aipatutako sailkapen batean baino gehiago sartzen zarelako, nik zurea bizi izan nuen bezala nik beste sufritu duzulako tesi hau, eta denbora guzti honetan eskaini duzun konplizidadeagatik.

Bestalde, mila esker emakumeok ikerketan jardutea posible egin duzuen aitzindari guztiei!
Eskerrik asko baita ikertzaileon borrokarekin bat egin duzuenei, gure errealitatea ulertu eta zabaldu duzuelako.

Baina, existentzialista jarrita, tesi hau ezin izango nuke burutu uhin hauen iturri eta sostengu den nire familia gabe. Mila esker danei, izeko, osaba, lehengusina, lehengusu, neba eta gurasoei. Bereziki, Ama, Aita eta Aitorri, ikasteko grina, pertseberantzia, ingurumenarekiko errespetua eta gure inguruan duguna ulertzeko grina erakusteagatik.

Berandu baino lehen amaitu behar zen tesi hau (eta *eskerrak*, bi zentzuetan)…

"Denoi gustatuko litzaiguke gauza onek betirako irautea. Baina, azkenean, iraun behar dutena irauten dute. Normalean beharrezkoa baino gehiago"- *Francis Diez (euskaratua)*

Aurkibidea/Content

AKRONIMOAK eta LABURTZAPENAK/ACRONYMS and ABBREVIATIONS

Acronym	Akronimoa	Meaning	Esanahia
B	**B**	Magnetic flux density	Fluxu magnetikoaren dentsitatea
COSMOS	**COSMOS**	Cohort Study of Mobile Phone Use and Health	Mugikorraren erabilera eta Osasuna ikertzeko kohortea
DECT	- **(Hari gabeko telefonoa)**	Digital Enhanced Cordless Telecommunications	
-	**DDT**		Dikloro Difenil Trikloroetanoa
Downlink	- **(Beheranzko lotura)**	Mobile phone downlink, descendant union, from antenna to the devices	Telefonia mugikorreko antenatik telefono mugikorrera doan seinalea
DVB-T	- **(Telebista antenak)**	Digital Video Broadcasting-Terrestrial	
E	**E**	Electric field	Eremu elektrikoaren intentsitatea
ELF	**ELF**	Extremely Low Frequency	Oso maiztasun txikiko uhinak
ELF-EF	- **(ELFen eremu elektrikoa)**	Extremely Low Frequency-Electric Field	
ELF-MF	- **(ELFen eremu magnetikoa)**	Extremely Low Frequency-Magnetic Field	
EMF	**EEM**	Electromagnetic Field(s)	Eremu elekromagnetikoa(k)
EMF-NIR	**EEI-EEM**	Electromagnetic Fields of Non-Ionizing Radiation	Erradiazio ez-ionizatzaileko eremu elekromagnetikoak
EPA	**EPA**	Environmental Protection Agency	Estatu Batuetako ingurumenaren babeserako agentzia

AKRONIMOAK eta LABURTZAPENAK/ACRONYMS and ABBREVIATIONS (continued)

Acronym	Akronimoa	Meaning	Esanahia
G	**G**	Gauss	Gauss
GERoNiMO	**GERoNiMO**	Generalised EMF research using novel methods. An integrated approach: from research to risk assessment and support to risk management	EEI-EEMen ikerketa orokorra, metodo berriak erabiliz. Ikuspegi integratua: ikerketatik arriskuen ebaluaziora eta arriskuen kudeaketan laguntza
GSM	**GSM**	Global System for Mobile Communications	Telefonia mugikorrerako sistema globala
H	**H**	Magnetic field	Eremu magnetikoaren intentsitatea
Hz	**Hz**	Hertz	Hertz
IARC	**IARC**	International Agency for Research on Cancer	Minbiziaren ikerkuntzarako nazioarteko agentzia
ICNIRP	**ICNIRP**	International Commission on Non-Ionizing Radiation Protection	Erradiazio ez-ionizatzaileen babeserako nazioarteko batzordea
LOQ	**-**	Limit Of Quantification	
IF	- **(Bitarteko maiztasunak)**	Intermediate Frequency	
IF-EF	- **(Bitarteko maiztasunen eremu elektrikoa)**	Intermediate Frequency-Electric Field	
IF-MF	- **(Bitarteko maiztasunen eremu magnetikoa)**	Intermediate Frequency-Magnetic Field	
IR	**EI**	Ionizing radiation	Erradiazio ionizatzailea

AKRONIMOAK eta LABURTZAPENAK/ACRONYMS and ABBREVIATIONS (continued)

Acronym	Akronimoa	Meaning	Esanahia
INMA	**INMA**	Environment and childhood (from INfancia y Medio Ambiente) cohort	Ingurumena eta Haurtzaroa
ITU	**ITU**	International Telecommunication Union	Nazioarteko telekomunikazio elkartea
Mobi-Expo	**-**	Characterization of the use of mobile phones in children, adolescents, and young adults	
NIR	**EEI**	Non-ionizing radiation	Erradiazio ez-ionizatzailea
Rembrandt	**-**	Radiofrequency ElectroMagnetic fields exposure and Brain Development	
RF	**IM**	Radiofrequency	Irrati-maiztasuna
S	**S**	Power density	Potentzia-dentsitatea
SCENIHR	**SCENIHR**	Scientific Committee on Emerging and Newly Identified Health Risks	Osasunerako Arrisku Emergenteen Zientzia Batzordeak
µT	**µT**	Microtesla	Mikrotesla
T	**T**	Tesla	Tesla
THD	**-**	Total Harmonic Distortion	
TWA	**TWA**	Time-Weighted Average	Denboragatik doitutako batez bestekoa
Uplink	- **(Goranzko lotura)**	Mobile phone uplink	Mugikorretik edo aparailu igorletik antenara doan seinalea
UMTS	**-**	Universal Mobile Telecommunications System	
V	**V**	Volt	Volt
W	**W**	Watt	Watt

AKRONIMOAK eta LABURTZAPENAK/ACRONYMS and ABBREVIATIONS (continued)

Acronym	Akronimoa	Meaning	Esanahia
µW	**µW**	Microwatt	Mikrowatt
WHO	**MOE**	World Health Organization	Munduko Osasun Erakundea
WiFi	**WiFi**	Wireless Internet connection	Hari gabeko interneta
Wimax	**-**	Wireless Internet connection, used mainly in rural areas	

LABURPENA

Erradiazio ez-ionizatzaileko eremu elekromagnetikoek (EEI-EEM) osasunean izan ditzaketen ondorioen inguruko kezkak handitzen joan dira azken urteotan, eremu horiek sortzen dituzten iturrien erabilera handitzearekin batera. Horrez gain, ikertzaileen artean ez dago adostasunik EEI-EEMek izan ditzaketen osasun efektuen inguruan, askotan ikerketen metodologia-mugak direla eta, esposizioaren neurketarekin zerikusia dutenak azpimarratu daitezkeelarik. Horregatik, tesi hau, esposizioaren ezaugarritzean zentratu da, 8 urteko umeek oso maiztasun txikiekiko (ELF), bitarteko maiztasunekiko eta irrati-maiztasunekiko (IM) duten esposizioaren ezaugarritzea burutuz. Bestalde, esposizio mailak dena delakoak izan arren, EEI-EEMen arriskuen pertzepzio altua izateak osasun arazoak eragin litzakeela eta, garrantzitsua da biztanleria orokorrak duen pertzepzioa eta berau azaltzen duten mekanismoak ezagutzea. Hori dela eta, aipatutako umeen amek EEI-EEMen inguruan zuten pertzepzioa jaso zen tesi honetan. Ikerketa INMA (Ingurumena eta haurtzaroa) kohortearen parte izan da, zeina ikerketa epidemiologiko prospektibo bat da, hasiera batean 638 ama eta seme-alaba bikotez osatua, ingurumen eragileekiko esposizio goiztiarrek haurren garapenean eta osasunean duten eragina ikertzen duena.

Tesi honetan EEI-EEMen maiztasun tarte guztiak kontuan izan dituen metodologia aurkeztu da. Era ezberdinetako neurketak egin ziren umeek egunean zehar denbora gehien ematen duten lekuetan, hots, etxe, eskola eta parkeetan, lagin batean IMen neurketa pertsonalak egiteaz gain. Metodologien arteko konparazioa gauzatu da, komunitate zientifikoak egokienentzat dituen metodologiak (baina denbora edo ditu iturri handiak eskatzen dituztenak) esfortzu (ekonomiko edo bestelakoa) gutxiago eskatzen duten batzuengatik ordezkatu daitezkeen edo ez ikertzeko asmoz.

Tesi honen emaitzak hiru atal nagusitan sailka daitezke; ELF eta bitarteko maiztasunen esposizioaren ezaugarritzea; IMen esposizioaren ezaugarritzea; eta amek EEI-EEMen inguruan duten pertzepzio mailen ebaluazioa.

ELF eta bitarteko maiztasunei dagokienez, oso informazio gutxi dago ELFen eremu elektrikoaren mailen inguruan eta bitarteko maiztasunen eremu elektriko zein magnetikoaren inguruan. Tesi honen helburuetako bat ELF eta bitarteko maiztasunen esposizioa ezaugarritzea izan zen, INMA kohortearen baitako umeengan. 104 etxe, 26 eskola (ikasgela eta jolastokietan) eta 105 parkeetan egin ziren neurketa puntualak eta iraupen luzeagokoak (24 ordukoak etxe zein eskoletako ikasgeletan eta 20 minutukoak eskolako jolastoki eta parkeetan). ELFen eremu magnetikoaren oso balio baxuak aurkitu ziren (24 orduko neurketetan lortutako batez besteko

handiena 0,15 µT izan zen etxe batean). Maiztasun tarte honen eremu elektrikoa, aldiz, beste ikerketa batzuetan ikusitakoaren antzekoa izan zen eta aldakortasun handiagoa aurkitu zen. Hala, kuartilartea 1 eta 15 V/m arteakoa izan zen barnealdean eta 0,3 eta 1,1 V/m artekoa kanpoaldean. Baliorik altuena 55,5 V/m izan zen eskola bateko jolastokian. Bitarteko maiztasunen kuartilartea 0,02 eta 0,23 µT izan zen eremu magnetikoarentzat eta 0,2 eta 0,5 V/m artekoa eremu elektrikoarentzat. Bitarteko maiztasunen balio maximoak bi eremu horientzat 0,03 µT eta 1,51 V/m izan ziren hurrenez hurren, eta biak etxeetan behatu ziren. Eremu elektriko eta magnetikoaren arteko korrelazioak baxuak izan ziren ELFen kasuan (Spearman korrelazioa 0,04tik 0,36ra ingurune ezberdinetan) eta neurrizkoa bitarteko maiztasunen kasuan (0,28 eta 0,75 bitartean). Etxean neurtutako ELFen eremu magnetikoaren bidez eta eskola, etxe eta parkeetan egindako neurketa puntualetan oinarrituta dauden denboragatik doitutako batez bestekoen (TWA) bidez egindako klasifikazioen artean neurrizko komunztadura lortu zen (Cohen κappa= 0,58) eta komunztadura hobea, funtsezkoa, lortu zen eremu elektrikoarentzako (Cohen κappa = 0,76). Orokorrean, gure kohorteko umeek ELFen eremu magnetikoarekiko oso esposizio baxua zuten azterturiko ingurune guztietan eta eremu elektrikoekiko esposizioa beste ikerketa batzuetan ikusitakoaren antzekoa izan bazen ere, etxeetan maila handiagoak neurtu ziren. Ikerketako parte-hartzaileen bitarteko maiztasunekiko esposizioak berdintsuak izan ziren leku guztietan.

IMei dagokienez, ez dago argi umeak maiztasun hauen esposizioarekiko sentikorragoak diren edo ez. Horregatik, ELF eta bitarteko maiztasunekin gertatzen den bezala, umeen esposizioa era egokian ezaugarritzea funtsezkoa da ikerketa epidemiologikoak gauzatu ahal izateko. Neurketa pertsonalek norbanakoaren informazioa ematen dute baina diru eta denbora aldetik esfortzu handia dakarte, batez ere ikerketa epidemiologiko handietan. Beste metodologia batzuk, neurketa puntualetan oinarrituta dauden denboragatik doitutako batez bestekoak kasu, lana asko errez lezakete. Tesi honetan, 104 etxe, 26 eskola eta 105 parkeetan neurketa puntualak egiteaz gain, 50 umez osatutako lagin txiki batean hiru eguneko neurketa pertsonalak burutu ziren eta hainbat eratan kalkulatutako TWAekin alderatu ziren. Neurketa puntualekin lortutako esposizioaren medianak 29,73 (umeen logeletan) eta 200,10 $\mu W/m^2$ (eskoletako jolastokietan) artean egon ziren eta balio handiagoak aurkitu ziren kanpoaldean barnealdekoekin alderatuz. Neurketa pertsonalen mediana 52,13 $\mu W/m^2$ izan zen eta neurketa puntualetan oinarritutako TWAen medianak 25,46 eta 123,21 $\mu W/m^2$ artean ibili ziren. Ikerketa honetan neurtutako esposizioak beste ikerketetan lortutakoen tartearen barruan daude. IMen esposizio totalean gehien eragin zuten iturriak FM irratirako antenak, telefono mugikorreko antenak eta telebistarako antenak izan ziren. Barnealdeko edota erabilera pertsonalerako iturriek oso gutxi eragin zuten IM totalean (denek batera <%20).

Neurketa pertsonalen eta neurketa puntualetan oinarritutako beste metodologien artean ezberdintasun esanguratsua behatu zen, zeina dentsitate potentziaren araberakoa izan zen. Neurketa puntualekin estimatutako esposizioa pertsonalekin estimatutakoa baino altuagoa izan zen. Aitzitik, subjektuak metodologia hauen bidez lortutako esposizioaren araberako kategorietan sailkatzerakoan, ez zen ezberdintasun sistematikorik ikusi, nahiz eta neurketa pertsonal bidez lortutako klasifikazioaren eta neurketa puntualen bidez lortutakoaren arteko akordioa neurrizkoa izan kasurik onenean (Cohen kappa=0,49).

Neurketa puntualetan oinarritutako esposizioaren ebaluazioa umeek IMekiko duten esposizio pertsonalaren arabera sailkatzeko baliagarria izan litekeela ondorioztatu da tesi honetan, beti ere beharrezkoak diren ingurune guztietan neurketak egiten diren bitartean.

Azkenik, gure kohorteko amen EEI-EEMen inguruko pertzepzioari dagokionez, oro har, oso pertzepzio maila altuak aurkitu ziren, bai ELFentzat bai IMentzat eta bai esposizio pertzepzioarentzat zein osasunerako arriskuaren pertzepzioarentzat, 10 puntuko eskalan 7 eta 8 inguruko batez besteko eta medianekin. Informazioa emateak ez zuen eraginik izan osasunerako arriskuaren pertzepzioan baina IMen esposizio pertzepzioa era esanguratsuan jaitsi zen (0,7 puntu) informazioa jaso eta gero. Bestalde, pertzepzioaren eta etxean neurtutako esposizio mailen artean ez zen erlaziorik aurkitu. Pertzepzio maila altuagoak behin baino gehiagotan (galdera batean baino gehiagotan) azaltzen zituzten aldagaiak ondorengoak izan ziren: klase sozial eskulangilea izatea, hiri-ingurunean bizitzea, auzo on batean bizitzearen sentipena izatea, aire kutsadura arazoak direla eta leihoa irekitzeak molestia sortzea, gazteagoa izatea eta etxean aparailu elektriko gutxiago izatea. Parte-hartzaile gehienek erakunde publikoengandik EEI-EEMen inguruan informaziorik jaso ez dutela edo nahikoa jaso ez dutela uste zuten eta oso garrantzitsutzat jo zuten informazioa jasotzea.

1. SARRERA

1.1. AURREKARIAK

Ingurumenaren bizi-kalitatea murriztean, gizakiaren bizi-kalitatea murrizten da - George Holland

Lurra bere parte garen komunitate gisa ikusten dugunean, orduan, agian, errespetuz eta maitasunez tratatuko dugu - Aldo Leopold

INGURUMEN KUTSATZAILEAK

Gure inguruneak erabat baldintzatzen du gure bizimodua. Hala, orografia, ur baliabideekiko gertutasuna edota lur emankorrak izatea giltzarri izango dira edozein izaki bizidunen populazio bat leku batean finkatzeko orduan. Ingurumenak eta bizi-ohiturek gaixotasunen garapenean duten garrantziaz jabetzen aitzindaria izan zen Hipokrates (k.a. 460- k.a. 377) eta horretan oinarrituz "*De aere aquis et locis*" liburua argitaratu zuen. Gizakia ia edozer egiteko eta sortzeko gai dela uste duen garai moderno hauetan, premisa horiek ahaztuta dituela dirudi, harik eta ustekabean harrapatutako hondamendi batek inguratzen gaituenarekin harreman osasuntsua izatearen garrantzia gogorarazten digun arte. Ahaztutakoak berrikasten egongo bagina bezala. Inguratzen gaituena menperatu beharko bagenu bezala; inguratzen gaituena eta gu bi organismo ezberdin izango bagina bezala; sistema holistiko eta interaktibo bat osatuko ez bagenu bezala [1].

Naturan aurki daitezkeen zenbait elementu biologiko, kimiko zein fisiko bizidunentzat kaltegarriak izan daitezke. Horrez gain, batez ere industriaren garapenaren ondorioz kutsatzaile (batez ere kimiko) berri -edo aurretik bioerabilgarriak ez zirenak- andana aurki daitezke ur, aire zein lurrean. Bestalde, egun ematen ari den aldaketa klimatikoaren ondorioak osasunaren ingurumen-determinatzaileetan nabarituko dira [2,3]. Muturreko baldintzak (adibidez, muturreko beroa) eta hondamendi naturalak gero eta ohikoagoak bihurtuko dira. Era honetan, bektore-bidez garraiatutako gaixotasunak aldez aurretik agertzen ez ziren eremu geografikoetan agertuko dira. Era berean, alergenoak eta aire kutsadura areagotuko dira, ozono kontzentrazioen gorakada aipagarriarekin. 1979an James Lovelockek aipaturiko -eta Lynn Margullisek babesturiko- oreka kolokan jartzen egongo bagina bezala [1].

XX. mendera arte epidemiologia gaixotasun infekziosoak ikertzera mugatu zen. Kutsadurak osasunarekin duen interakzioa historian berandu aztertu da. Hala, ingurumen kutsatzaile batek minbizia sor dezakeela XVIII. mendean aipatu zen lehenengo aldiz, Percivall Pott zirujau ingelesak, hain zuzen ere. Tximinietako kedarra kentzen zutenek – askotan umeak, tximiniaren tamaina zela eta- eskroto minbizia garatzeko arrisku handiagoa zutela behatu zuen. Gaixotasun ez-infekziosoen inguruko epidemiologia modernoari ateak zabaldu zizkion aurkikuntza izan zen. Hurrengo mendean Edwin Chadwickek gaixotasunak bizi-ohiturekin erabat erlazionatuta zeudela baieztatu zuen, eta osasun publikoaren garapena eta gizarte erreforma beharrezkotzat jo zituen, uren kalitatearen eta arazketaren beharra goraipatuz. Mende berean, Londreseko auzo batean bizi edo lan egiten zutenengan kolera kasuen gorakada aztertu zuen John Snow mediku ingelesak, teknika epidemiologiko eta espazialez baliatuz, jatorria iturri jakin bateko uraren kutsadura zela ondorioztatu zuen arte. Egun, epidemiologia modernoaren aitzindari gisa jotzen da –nahiz eta tamalez izen bereko fikziozko pertsonaia ezagunagoa izan-. Ingurumenaren eta osasunaren babesaren bideak elkartzeko joera egin zuen gutxika. Ildo honetan, 1962an argitaratu zen "*Silent Spring*" liburuarekin mugimendu ekologistaren sorrera eta sustantzia xenobiotikoen inguruko ardura hasi, edo behintzat hazi zen [4]. Rachel Carson itsas biologoak eta dibulgatzaileak pestizidek ekosistemetan eragin kaltegarriak zituztela defendatu zuen liburu hartan, eta bere lana beharrezkoa izan zen Dikloro Difenil Trikloroetanoa (DDT) debekatzeko eta beste zenbait konposatu organiko iraunkorren inguruko ikerketak egiten hasteko. Estatu Batuetako ingurumenaren babeserako agentzia (Environmental Protection Agency, EPA) sortzea ere bere behaketen zeharkako beste ondorioetako bat izan zen. "Historian lehen aldiz izaki oro produktu kimiko arriskutsuekin dago kontaktuan, jaiotzetik heriotzaraino […] arrainetan, mendietako urrutiko lakuetan, lurrean lurperatutako zizareetan, hegaztien arrautzetan eta gizakian beregan […]. Amaren esnean daude eta oraindik jaio ez den umearen ehunetan ere ziur aski" [4]. Azken esaldi hori, egun ikerketa askoren funtsezko hipotesia da. 1993an definitu zuen Munduko Osasun Erakundeak (MOE) ingurumen osasuna. Ingurumenaren faktore fisiko, kimiko, biologiko, sozial eta psikosozialek determinatzen duten giza osasunaren alderdiak hartzen ditu, bizi-kalitatea barne. Gaur egungo eta etorkizuneko belaunaldien osasunean eragina izan dezaketen ingurumen alderdien ebaluazioa, zuzenketa, kontrola eta prebentzioa ere hartzen ditu aintzat [5].

Nahiz eta azken urteotan ingurumen kutsatzaileen inguruko ikerketak areagotu, zalantzak ere ugarituz doaz; sustantzia berrien agerpenak; mekanismo biologikoen inguruko ezjakintasuna; edota Paracelsusen dosiaren inguruko adierazpenen birplanteatzea [6] egungo toxikologiak eta osasun publikoak dituzten erronken adibideak besterik ez dira.

Azken urteotan, kutsatzaile kimiko eta biologikoez gain, kutsatzaile fisikoen ikerketari ekin zaio. Zarata batez ere hirietako kutsatzaile garrantzitsu bat izatera irisi da [7]; baldintza termohigrometrikoek gure bizimodua baldintzatzen dute; erradiazio ionizatzailearen eragina ezagututa arma gisa erabili izan dute eta nahi dute batzuek... eta zer esan erradiazio ez-ionizatzailearen inguruan? Horrenbeste izu eragiten duten izpi ultramoreak eremu elektromagnetiko ez-ionizatzaile direla ahaztu gabe, hainbeste eztabaidaren sorburu den energia gutxiagoko eremuez jardungo gara hurrengo orrialdeetan, datuetan oinarritutako eztabaida sustatu nahian.

INGURUMENA ETA HAURTZAROA - INMA PROIEKTUA

Ingurumen kutsatzaileek izaki bizidun guztiengan eragin dezaketen arren, haur populazioari arreta berezia jarri behar zaio. Haurrak ez dira heldu txikiak, etengabeko garapenean dauden gizakiak baizik. Kutsatzaileek umea jaio aurretiko etapetatik bertatik eduki dezakete eragina, bere sistema eta organoen funtzionamendu egokia eragotziz. Jaio ondoren, gorputzeko organo eta sistemek garatzen diraute, eta agente xenobiotikoek garapen hori era egokian gertatzea galarazi dezakete. Umeen immunitate-sistema guztiz garatu gabe dagoela nabarmendu behar da, eta horrek helduak baino sentiberagoak egiten ditu.

Kutsatzaileak nonahi daude: ur, aire, lur zein janarian. Esposizio bide guztietatik sartuko dira kutsatzaileak gorputzean eta beharrezkoa da kutsatzaile ezberdinen pean egoteak eduki dezakeen ondorioak era integratu batean ikertzea.

Horrez gain, nahiz eta sustantzia xenobiotiko askoren eraginak ezagunak izan, oraindik kutsatzaile askok dosi txikietan duten eragina argitzeke dago. Gainera, informazio genetikoan sor ditzaketen asalduren inguruko zalantza ugari daude. Dena den, epigenetika baliagarria izango da zalantza horiek argitzeko.

MOEk 2002an eginiko Bangkokeko deklarazioan dosi baxuen peko esposizioek umeen jaio aurretiko garaietatik nerabezarora arte duten efektua ikertzeko beharra azpimarratu zuen [8].

Testuinguru honetan, ume populazioa ikergai duten hainbat ikerketa proiektu abiatu dira. Epidemiologiaren arloan, zenbait ume kohorte sortu dira herrialde ezberdinetan [9].

Espainian osasun publiko arloko hainbat ikerketa taldek, INMA (INfancia y Medio Ambiente-Ingurumena eta Haurtzaroa; www.proyectoinma.org) ikerketa sarea osatu zuten. Ingurumenak eta dietak fetuarengan eta umearengan dituen efektuak ikertzeko asmoz sortu zen 2003an. Guztira zazpi kohorte prospektibok osatzen dute sarea [10,11] (1. irudia).

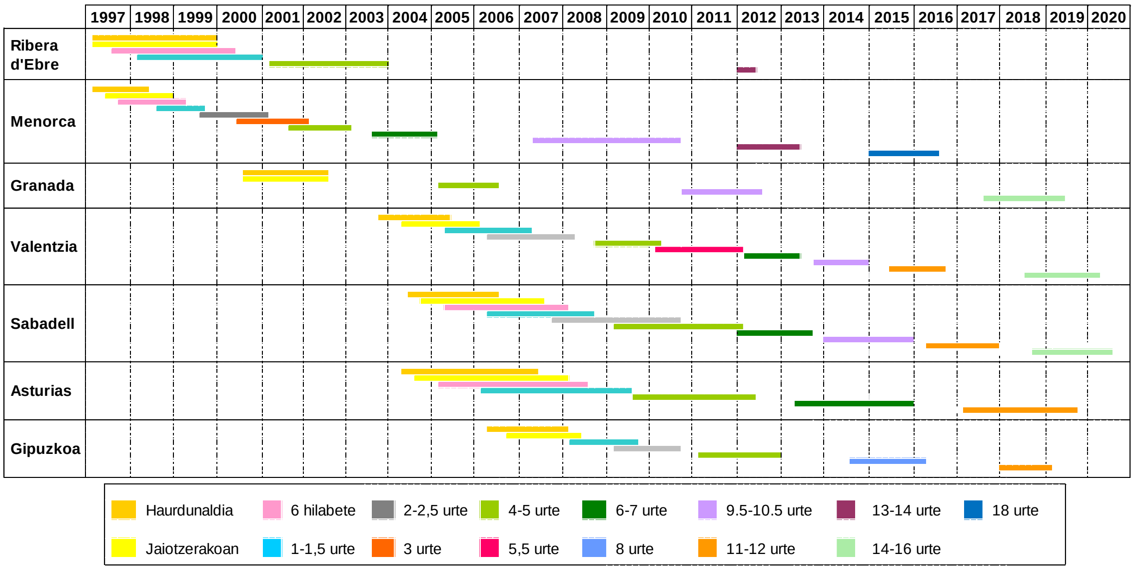
1. irudia: INMA sarea osatzen duten kohorteen kokapena (http://www.proyectoinma.org)

Ebro itsasertzekoa (n=102), Menorcakoa (n=530) eta Granadakoa (n=668) aitzindari eta eredu izan ziren gainontzekoentzat. Hala, lehenengoak, Flixeko enpresa batek isuritako konposatu organokloratuek eta merkurioak neurogarapenean zuten eragina aztertzeko xedea zuen; Menorcakoa airean dauden alergeno eta sustantzia narritagarriek alergia eta asmarekin duten erlazioa aztertzeko sortu zen; Granadakoak disruptore endokrinoen eta ugalketa arazoak ikertzeko helburu nagusia zuen. Hauek garatutako protokoloak oinarrizkoak izan ziren kohorte berriagoentzat: Valentzia (n=855), Sabadell (n=657), Asturias (n=494) eta Gipuzkoa (n=638).

INMA proiektuak hiru **helburu** nagusi ditu:

1. Ingurumen kutsatzaileekiko haurdunaldiko esposizioa deskribatzea eta haurdunaldian, jaiotzean eta haurtzaroan zehar fetu edota umearen barne-dosia kalkulatzea
2. Kutsatzaile ezberdinen pean egoteak fetuarengan eta umearen hazkuntza, osasun eta garapenean duen eragina aztertzea
3. Kutsatzaileen, elikagaien eta geneen artean dagoen interakzioa aztertzea, fetuarengan eta umearen hazkuntza, osasuna eta garapenean duten eraginari dagokionean

Gipuzkoako kohortea 2006 eta 2008 artean jaiotako umeek osatzen dute. Erreferentzia ospitale gisa Zumarragakoa zuten amei, haurdunaldiaren lehenengoko mediku bisitan, ekografia egitera joandakoan, proposatu zitzaien proiektuan parte hartzea. Inklusio-irizpideak aurretik argitaratutako publikazioetan aurki daitezke [10,11]. Urteetan zehar galdetegi, lagin biologiko eta ingurumen laginketen bidez hainbat kutsatzaileekiko esposizioa kalkulatu da eta eraginak ikusi dira azterketa fisikoak eta neurogarapenekoak eginez besteak beste. Jarraipenen maiztasuna eta iraupena kohortearen araberakoa da. Tesi hau umeen 8 urteko jarraipen fasearen barne garatu da. 2. irudian dugu momentura arte eginiko jarraipenen adierazpena.



2. irudia: INMA kohorte guztien jarraipen faseak. www.proyectoinma.org web orritik moldatuta.

Proiektua martxan egon denetik kutsatzaile ugari aztertu ditu, baina batez ere, kutsatzaile kimikoak izan dira aztergai. Gizarteak beste kutsatzaile batzuekiko kezka ere badu. Esaterako, asko dira telefonia mugikorreko antena edo tentsio altuko linea baten ondoan bizitzeagatik kexu direnak, euren osasunerako kaltegarriak direlakoan. Era honetan, INMA proiektuan osasunean eragin dezaketen aldagai anitzen informazio andana dagoela baliatuz, eremu elektromagnetiko ez-ionizatzaileak aztertzea onestu zen.

Behatu natura sakonki eta dena ulertuko duzu hobeto - Albert Einstein

ENERGIA, KOMUNIKAZIOA ETA EREMU ELEKTROMAGNETIKOAK

Eguneroko ekintza guztiek zera dute amankomunean: energiaren beharra. Landare baten hazkundeak, edozein mugimenduk eta funtsean izaki ororen bizitzak berak behar horixe du. Izaki bizidunok jatorri ezberdineko elikagaietatik (materia organiko zein inorganiko) eta eguzkitik lortzen dugu bizitzeko beharrezko energia. Gure arbaso zen *Homo erectus*ek sua deskubritu zuenetik gizakiaren bizitza erabat aldatu da, bai osasun aldetik eta bai praktikotasun aldetik, aurkikuntza horrek hainbat ondorio izan zituelako, hala nola hotzetik babestea, argi iturria izatea edota elikagaiak prestatzea eta digestioa erraztea. Ordutik energiaren lorpenak eboluzio handia izan du, baina betiere naturan dauden iturriak ustiatu izan dira. Gure bizitza erraztu nahian, gizakiaren lana egingo luketen makinen bila ibili gara, eta aurrerapen nabarmenak egin dira energiaren ekoizpenean eta elektrizitatean, batez ere produkzioa igo nahi izan zen industrializazio garaian.

Bestalde, gazteenek sinetsiko ez balute ere, izan ziren hari gabeko komunikazioa existitzen ez zeneko garaiak. Hein batean Nikola Tesla eta Guglielmo Marconi aitzindariei zor diogu gaur egun hain normaltzat dugun komunikazio sistema, lehenengokoak 1893an kable gabeko energiaren transmisioa burutu zuen eta bigarrenak lehenengo irrati birtransmisioa egin zuen 1895ean. Zalantza barik, gaur egungo gizartearen ezaugarri den gauzarik garrantzitsuenetarikoa bilakatu da komunikazio azkar eta globala.

Baina bai energiaren sorrera, garraio eta erabilera, bai hari-gabeko komunikazioa, erradiazio ez-ionizatzaileko eremu elektromagnetikoen (EEI-EEM) iturri dira. Funtsean, aldi berean mugitu eta argiaren abiaduran ($\approx 3 \times 10^8$ m/s) hedatzen diren uhin elektriko eta magnetikoen arteko konbinazioari deritzo eremu elektromagnetikoa, eta uhin mekanikoak ez bezala, hutsean ere garraia daitezke.

Fenomeno elektriko eta magnetikoak greziarren garaitik dira ezagunak. «Elektriko» hitza greziarrez “anbar” esanahia duen *elektron* hitzetik eratorria da. Anbarra artilearekin igurztean lastoa edota lumak erakartzen zituela ikusi zen. 1600. urtean William Gilbertek, elektrifikazioa anbarraren gauza espezifikoa ez zela egiaztatu zuen. Bestalde, magnetitak (Fe_3O_4) burdinarekiko erakarpena zuela ikusi zen. Magnetiko hitza magnetita aurkitu zen lurraldetik eratorri zen, Magnesiatik (Grezia) alegia [12].

Burdin hari bat iparrorratzaren edota imanaren ondoan jartzerakoan, orratza eta imana mugitzen zirela ikusi zuten Hans Oersted eta Michael Faradayk, hurrenez hurren. Aurkikuntza horiek oinarri moduan izan zituen Clerck Maxwellek egun hain ezagunak diren elektromagnetismoaren legeak garatzeko. Maxwellek, korronte elektrikoak eremu magnetikoa sortzen zuela egiaztatu zuen. Heinrich Hertzek Maxwellen legeak erabili zituen laborategian uhin elektromagnetikoak sortzeko. Hertzek uhin elektromagnetikoen uhin-luzera eta abiadura neurtu zituen, eta uhin horien isla eta errefrakzioa argiarenak bezalakoak zirela frogatu.

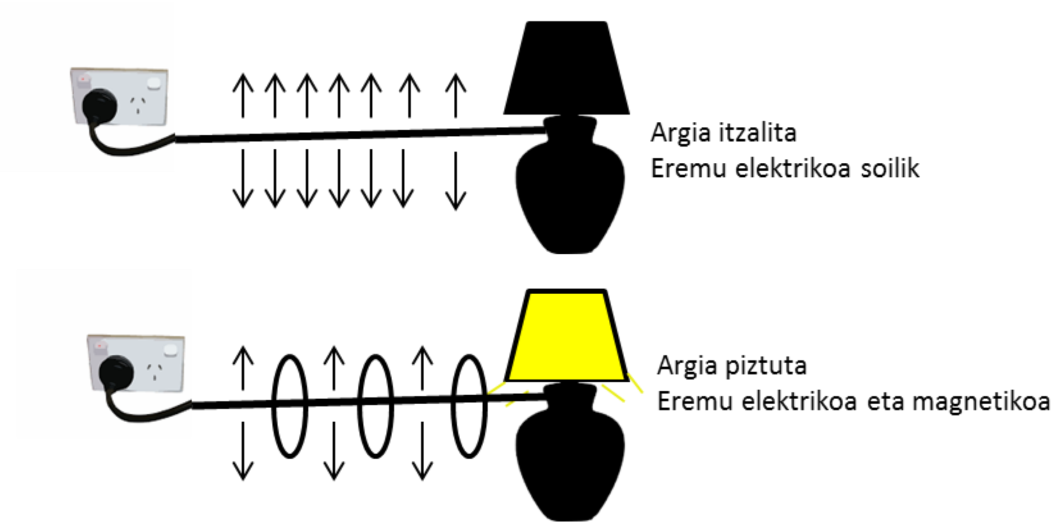
Objektu guztiak atomoz osaturik daude eta hauek egoera neutroan daudenean nukleoan duten protoi beste elektroi dituzte orbitan, nukleoaren inguruan. Protoiak ez bezala, elektroiak material batetik bestera transferitu daitezke, ioiak eta ondorioz karga elektrikoa sortuz. Material isolatzaileek kargen mugimendua ekiditen duten bitartean, eroaleek ez dute erresistentziarik jartzen. Eremu magnetiko eta elektrikoek karga elektrikoari zor diote euren existentzia. Bi eremuen ezaugarri nabarmenenak 1. Taulan ageri dira.

1. Taula

Eremu elektriko eta magnetikoen ezaugarri aipagarrienak

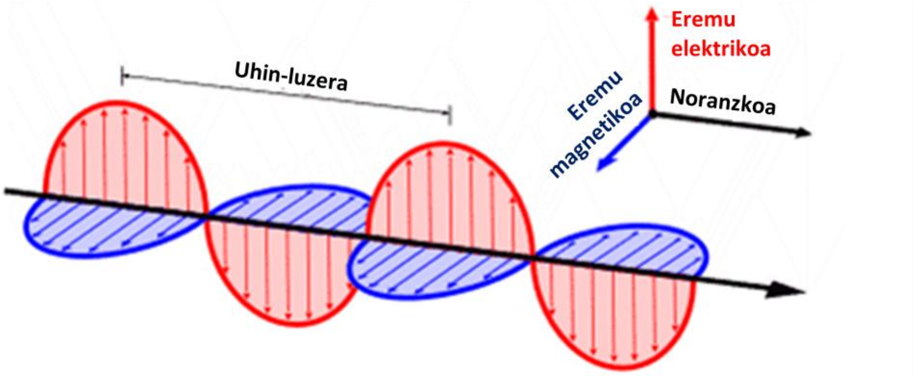
Eremu elektrikoak		Eremu magnetikoak
Kargen artean dauden indarrak deskribatzen ditu. Jatorria: Tentsio diferentzia	≠	Korronteen artean dauden indarrak deskribatzen ditu. Jatorria: Mugimenduan dauden kargak
Puntu batean dagoen intentsitatea: eremuak puntu horretan dagoen kargaren gainean eginiko indarra (Voltio/m)	≠	Intentsitatea: Eroaletik igarotzen den elektroi karga neurtzen du, Tesla (indukzio magnetikoa) edo Anperio/m-tan. Tesla= 7.96 .10^5 A/m
Korrontea egon ez arren existitzen da eta tentsioarekiko proportzionala da	≠	Aparailu elektriko bat martxan egon eta korrontea garraiatzean soilik daude eremu hauek (ikus 3. irudia)
Distantziarekin ahultzen dira	=	Distantziarekin ahultzen dira
Material batzuek oztopatzen dute (egurrak, beirak eta plastiko askok kasu)	≠	Ohiko materialek ez dute blokeatzen

Bi eremuen arteko desberdintasuna ikusteko adibiderik garbiena, lanpara sare elektrikora konektatzerakoan dugu. Sare elektrikora konektatua egote hutsarekin eremu elektrikoa sortzen da, baina lanpara pizterakoan, elektroien mugimenduarekin batera eremu magnetikoa ere sortzen da (3. irudia).



3. irudia: Eremu elektrikoa eta magnetikoa noiz dauden adierazteko adibidea

Eremu magnetikoa eta elektrikoa euren artean perpendikularrak dira eta uhinen hedatze norabidearekiko ere perpendikularrak dira (4. irudia).



4. irudia: eremu elektriko eta magnetikoen adierazpen grafikoa. *Iturria:* *physics.stackexchange.com*, moldatua

Euren ezaugarri bereizgarrien artean, maiztasuna eta uhin-luzera daude. Nikola Teslak sustatu zuen korronte alternoan, jarraian ez bezala, korronteak noranzkoz aldatzen du denboran zehar. Maiztasunak (f) aldaketa hori neurtzen du; segundoko egiten diren zikloak zehazten ditu, hain zuzen ere, eta Hertziotan (Hz) neurtzen da. Uhin-luzerak (λ), aldiz, korronte elektrikoak ziklo batean egiten duen distantzia neurtzen du metrotan. Hori kontuan izanda, maiztasuna eta uhin-luzera alderantziz proportzionalak dira. Hala, maiztasun txikiko uhinek uhin-luzera handia dute eta alderantziz. Bi propietateen arteko erlazioa ondorengo formulek azaltzen dute:

$$\lambda = \frac{v}{f}$$

$$\lambda = \frac{c}{f}$$

non v uhinaren abiadura eta c argiaren abiadura hutsean diren. Uhinaren energia, maiztasunarekiko zuzenki proportzionala da, hurrengo eran:

$$E = h \cdot f$$

non h Planck-en konstantea den (6,63 x 10^{-34} J·s edo 4,136 x 10^{-15} eV)

Espektro elektromagnetikoak maiztasunaren arabera sailkatzen ditu uhinak (ikus sarrerako 1.2 atala). Maiztasun handiena dutenak eta beraz uhin-luzera txikiena dutenak, espektroaren eskuinaldean kokatzen dira. Hauei erradiazio ionizatzaileko eremu elektromagnetiko deritze (EI-EEM) eta jakina da euren energia nahikoa dela lotura kimikoak apurtu eta atomoak ionizatzeko. Aldiz, espektroaren ezkerraldean kokatzen diren EEI-EEMek (>0 Hz-300 GHz) ez dute lotura horiek apurtzeko besteko energiarik, eta osasunean sor ditzaketen ondorioak ezbaian daude [13].

EEI-EEM osatzen duten hiru talde nagusiak ondorengoak dira (1.2 atalean sakonago azaldua):

- Oso maiztasun txikiko uhinak (ingelesezko siglak: ELF, *Extremely Low Frequency*), >0-300 Hz maiztasun tartean daude, eta energiaren sorkuntza, garraio eta erabilerarekin lotuta daude.
- Bitarteko maiztasunak, 300 Hz eta 10 MHz arteko maiztasun tartean daude eta segurtasun-sistemak edo ordenagailu eta telebista-pantailak dira haien iturri nagusiak.
- Irrati-maiztasuneko uhinak (IM), 10 MHz eta 300 GHz arteko maiztasun tartean daude eta batez ere hari gabeko komunikazioarekin loturik daude.

Euren esposizioa ebaluatzeko, eremu hurbil eta urrunaren arteko desberdintasuna ulertzea ezinbestekoa da. Iturri baten inguruan eremu hurbila eta eremu urruna desberdintzen dira. Eremuen arteko muga iturrian dagoen uhin motaren araberakoa da, zehatzago esateko, bere uhin luzeraren araberakoa. Normalean uhin luzeraren hirukoitza den distantziara (metrotan) hasten da eremu urruna. Eremu hurbilean, eremu magnetikoa eta elektrikoaren arteko erlazioa ez da konstantea eta bereizi egin behar dira neurtzeko orduan, bakoitza bere aldetik neurtuz. Eremu urrunean, ordea, bi eremuak batera neurtzen dira, eremu elektromagnetiko gisa. Kasu honetan uhinak lauak kontsideratzen dira eta eremu elektrikoa neurtuta magnetikoa zenbatetsi daiteke eta alderantziz. Hortaz, ELF eta bitarteko maiztasunen uhinen kasuan, eremu hurbilean aurkitzen garenez normalean, eremu magnetiko eta elektrikoa bakoitza bere aldetik neurtzen da eta IMen kasuan bakarra neurtzearekin nahikoa da eta eremu elektromagnetikoaren balioa ematen da maiz.

Neurtzeko erabiltzen diren magnitudeak

300 GHz arteko erradiazio elektromagnetikoak neurtzeko, eremu elektrikoaren intentsitatea (**E**), eremu magnetikoaren intentsitatea (**H**), indukzio magnetiko edo fluxu magnetikoaren dentsitatea (**B**) eta potentzia-dentsitatea (**S**) magnitudeak erabiltzen dira.

Eremu elektrikoa definitzeko *eremu elektrikoaren intentsitatea (**E**)* erabiltzen da. Intentsitatea eremu elektrikoak karga-unitatea duen puntu baten gainean egindako indarra da. Magnitude bektoriala da eta bere hiru osagaiak erabiltzen dira bere modulua definitzeko:

$$\mathbf{E} = \sqrt{\boldsymbol{E_x}^2 + \boldsymbol{E_y}^2 + \boldsymbol{E_z}^2}$$

Intentsitatea metroko voltetan (V/m) neurtzen da. Distantziaren karratuarekiko alderantziz proportzionala da, eta horren ondorioz distantzia handitzean intentsitatea jaisten da.

Eremu magnetikoaren intentsitatea (**H**), **E** bezala, magnitude bektoriala da eta beraz, bere hiru osagaiak hartu behar dira kontuan. Metroko anpere (A/m) unitatea erabiltzen da. Eremu magnetikoa ere distantzia handitu ahala gutxitzen da.

Ikerketa epidemiologikoetan, **H**ren ordez, *indukzio magnetiko edo fluxu magnetikoaren dentsitatea* (**B**) erabiltzen da eremu magnetikoa deskribatzeko. Erabiltzen den unitatea Tesla (T) da eta askotan bere azpimultiploak, militesla (mT) eta mikrotesla (µT). Gaussa (G) ere erabil daiteke (1 T = 10.000 G).

Bi magnitudeak, **H** eta **B**, iragazkortasun magnetikoaren (µ) bidez erlazionatzen dira:

$$\mathbf{B} = \mu \cdot \mathbf{H}$$

µ-ren balioa materialaren araberakoa da eta hutsean $\mu_0 = 4\,\pi 10^{-7}$ H/m da.

Potentzia-dentsitatea (**S**), area unitateko potentziari deritzo. Eremu elektriko (**E**) eta magnetikoaren (**H**) arteko biderkadura bektoriala da, emaitzari **S** edo Poynting-en bektorea deritzolarik. Metro karratuko wattetan (W/m^2) edo zentimetro karratuko miliwattetan, (mW/cm^2) neurtzen da eta iturri ezberdinetako potentziak aritmetikoki batu daitezke.

IMak neurtzerako orduan **S** edo **E** erabiltzen dira. Iturri ezberdineko eremu elektrikoak batzeko (adibidez E1 eta E2 gehitzeko) ondorengo eran egiten da:

$$\mathbf{E}_{\text{batura}} = \sqrt{\mathbf{E_1}^2 + \mathbf{E_2}^2}$$

S eta **E**ren arteko erlazioa inpedantzia (Z_0) da. Urrutiko eremuan gaudenean, Z_0 konstantea da:

$$Z_0 = \frac{\mathbf{E}}{\mathbf{H}} = 120\pi \approx 377\Omega$$

$$\mathbf{S} = \frac{\mathbf{E}^2}{120\pi} = \frac{\mathbf{E}^2}{377}$$

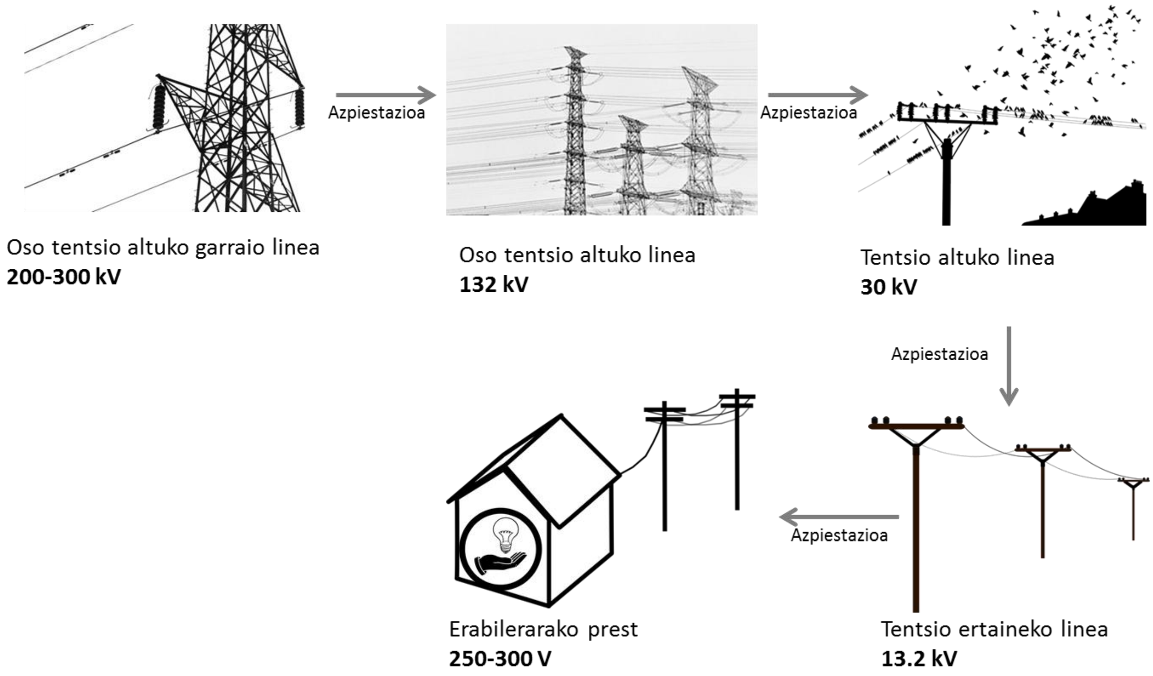
S W/m^2-tan, **E** V/m-tan

Beraz, **S**, **H** edo **E** jakinda beste biak ezagutu ditzakegu

EEI-EEMen iturriei buruzko kontzeptu batzuk

Energiaren sorrera, garraioa eta erabilera, ELFen sorkuntzaren testuinguruan.

Sistema elektrikoen maiztasuna Europan 50 Hz-takoa da eta Estatu Batuetan, Kanadan Erdialdeko Amerikan eta Asiako leku batzuetan, aldiz, 60 Hz-takoa. Edozein puntutan energiaren erabilera ahalbidetzea sistema elektriko konplexu bati esker lortzen da. Energia ekoizten den lekuetatik kontsumitzen den lekura arte garraiatu behar da. Tentsioa edo bi punturen arteko potentzial diferentzia karga elektrikoa puntu horien artean mugitzeko beharrezko lana da, voltetan neurtzen dena (aurrerantzean V). Tentsioa aldakorra da sistema elektrikoan zehar. Segurtasuna, ekonomia eta arrazoi teknikoak direla eta, ekoizpen zentroetan, garraio lineetan eta kontsumo puntuetan ezberdina izan behar da. Garraiatzeko energia gutxiago duten maiztasun txikiko uhinak eta tentsio oso altua erabiltzen da, energia galerak murrizteko asmoz. Tentsio hori gradualki jaitsi egiten da herrietan erabilgarria izateko, tentsio aldaketa transformatzaileetan eginez. Euskal Autonomia Erkidegoan erabiltzen diren egiturak eta tentsioak 5. irudian azaltzen dira.

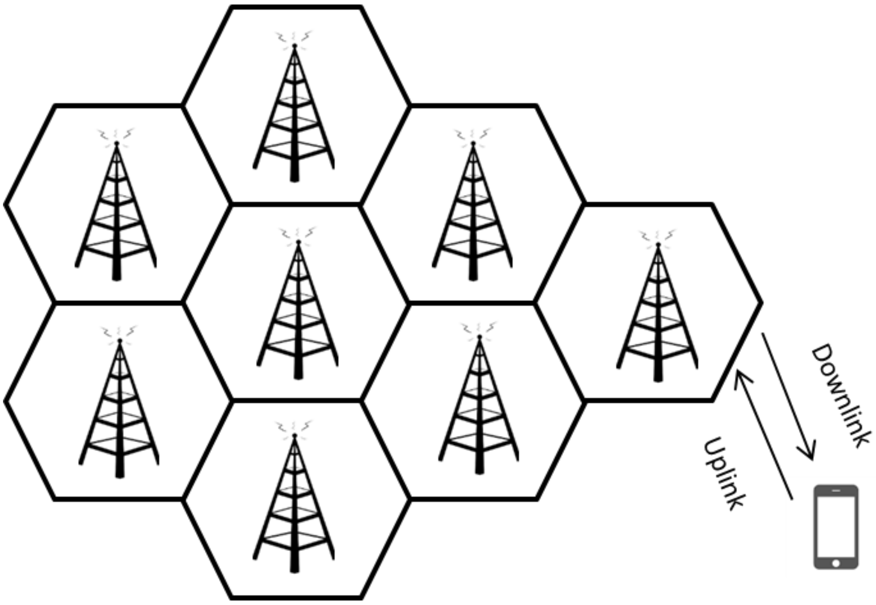


5. irudia: Sistema elektrikoaren eskema

Hari-gabeko komunikazioen erabilera, IMen sorkuntzaren testuinguruan.

Irrati, telebista, telefono mugikorreko antenak, WiFia, Bluetootha eta hari gabeko telefonoa dira IMak erabiltzen dituzten teknologien adibideak. Irrati uhinak igortzeko edo jasotzeko antenak erabiltzen dira. Antena igorleek seinalea noranzko batean kontzentratzen dute. Irrati eta telebistako antenek denboran zehar etengabeko transmisioa duten bitartean, WiFi eta mugikorrenek seinaleak igortzen dituzte denboran zehar.

Telefonia mugikorrera bideratutako estaldura zona ezberdinetan banatzen da (6. irudia). Zelula bakoitzean antenen estazio base bat kokatzen da. Zelulen tamaina erabileraren araberakoa izaten da. Hala, zelularik txikienak merkatal gune eta aireportuak bezalako leku jendetsuetan egoten dira (200 m artekoak) eta nekazal guneetan, aldiz, zelularik handienak (20 km artekoak). Estaldura hobea lortzen da sistema honen bidez, eta gainera, maiztasun ezberdinen arteko interferentziak txikiagotzen dira, komunikazioaren kalitatea hobetuz.



6. irudia: Zelulen egitura. Downlink: antenatik mugikorrera doan seinalea. Uplink: mugikorretik antenara doan seinalea.

1.2. Erradiazio ez-ionizatzaileko eremu elektromagnetikoen eraginak osasunean: ezagutza-egoeraz egun dakiguna [Health effects of non-ionizing electromagnetic fields: current state of knowledge]

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EKAIA 2016; 30: 105–123
DOI: 10.1387/ekaia.16148

LABURPENA

Gure bizimoduan gero eta ohikoagoak dira erradiazio ez-ionizatzaileko eremu elektromagnetikoak (EEI-EEM) sortzen dituzten iturriak, eta bere horretan dirau eremu horiek osasunean izan ditzaketen efektuen inguruko eztabaidak. Artikulu honetan laburbildu egin nahi ditugu EEI-EEMen eraginen inguruko ikerketa esperimentalen eta epidemiologikoen bidez lortu diren emaitzak. Nahiz eta ikerketa eta proiektu ugari egon gaiaren inguruan, kontu ugari daude argitzeke, batez ere metodologia-mugek sortzen dituzten arazoek ez dutelako ondorio argirik ateratzeko aukera ematen. Aurrerantzean, ahalegin handiagoak egin beharko lirateke eremu elektromagnetikoen esposizioaren estimazio egokiagoa egite aldera.

Hitz gakoak: Eremu elektromagnetikoak; erradiazio ez-ionizatzailea; osasun-kalteak; eremu elektromagnetikoen esposizioaren estimazioa.

ABSTRACT

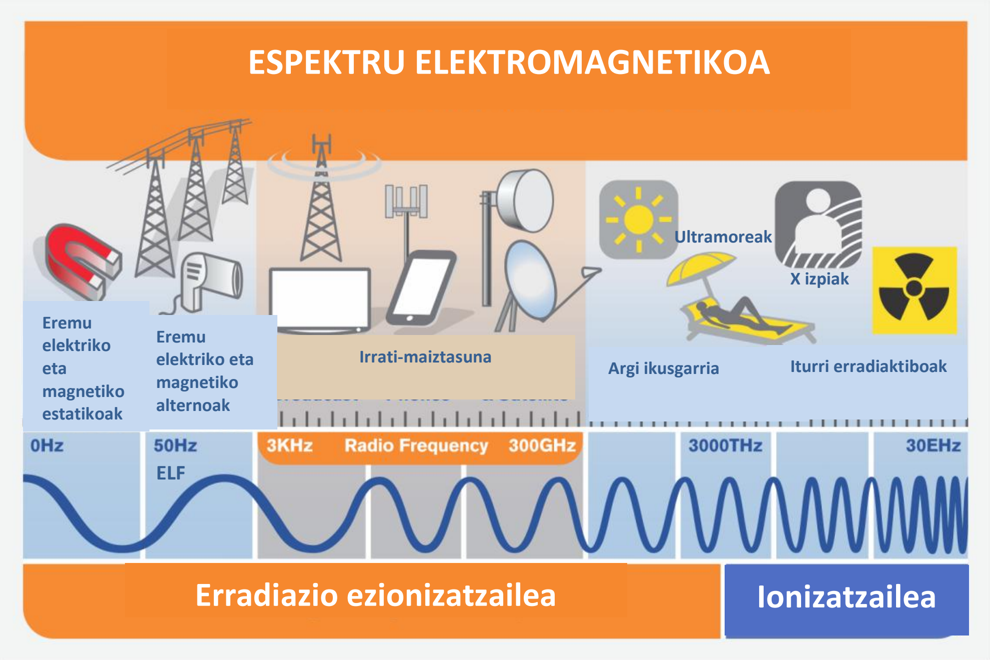
Sources of electromagnetic fields of non-ionizing radiation (EMF-NIR) are increasingly common in our lifestyle, while discussion regarding their potential health effects remains unclear. The aim of this study is to collect and summarize experimental and epidemiological studies published concerning health effects of EMF-NIR. Although there are plenty studies and projects on this subject, there are several unclear issues, especially because problems arising from methodological limitations preclude getting a clear conclusion. Greater effort should be made in the future in order to estimate better the exposure.

Keywords: Electromagnetic fields; non-ionizing radiation; health effects; exposure assessment.

SARRERA

Eremu elektromagnetikoak (EEM) uhin elektriko eta magnetikoen konbinazioak dira, eta aldi berean eta argiaren abiaduran hedatzen dira. Uhinek bi ezaugarri bereizgarri dituzte: uhin-luzera eta maiztasuna. Uhinaren ziklo oso bati dagozkion puntuen arteko distantzia da uhin-luzera, eta metrotan neurtzen da. Maiztasuna, aldiz, denbora unitateko uhinak egiten duen oszilazio kopurua da eta hertzetan (Hz) neurtzen da. Bi ezaugarriak euren artean alderantziz proportzionalak dira: maiztasun handiak dituzten uhinek uhin-luzera txikia dute.

Espektro elektromagnetikoak uhinen maiztasunaren arabera sailkatzen ditu EEMak (1. irudia). Bi talde handitan bereiz ditzakegu: erradiazio ionizatzaileak (EI) eta erradiazio ez-ionizatzaileak (EEI). Zenbat eta maiztasun handiagoa izan, hainbat eta handiagoa da daraman energia ere. EI-EEMak gai dira lotura kimikoak apurtzeko eta atomoak ionizatzeko, baina EEI-EEMek ez dute horretarako gaitasunik eta zientzialarien artean ez dago adostasunik azken hauek osasunean eragin ditzaketen ondorioei buruz. Argi ultramoreko uhinak eta argi infragorriko uhinak kontuan izan gabe, EEI-EEMak hiru talde nagusitan bereiz daitezke. Oso maiztasun txikiko uhinak (Ingelesezko siglak: ELF, *Extremely Low Frequency*), 0-300 Hz maiztasun tartean daude, eta energiaren sorkuntza, garraio eta erabilerarekin lotuta daude. Tentsio baxuko, ertaineko edo altuko lineak, transformadoreak edota sare elektrikoaz hornitzen diren etxetresnak dira iturri nagusienak. Bitarteko maiztasunak, 300 Hz eta 10 MHz arteko maiztasun tartean daude eta segurtasun-sistemak edo ordenagailu eta telebista-pantailak dira haien iturri nagusiak. Irrati-maiztasuneko uhinak (IM) batez ere hari gabeko komunikazioarekin loturik daude: hari gabeko telefonoa, sakelako telefonoa, bluetootha, WiFia eta antenak (sakelako telefonia, irrati eta telebista-antenak). Ikerketa gehienek ez dituzte bitarteko maiztasunak bereiz aztertzen, hots, erradiazio ez-ionizatzailea ELF eta IM taldeetan sailkatzen dute, bitarteko maiztasunak bi talde horien goi eta behe muturretan utzita.



1. irudia. Espektro elektromagnetikoa. Iturria: Moldatua Nazioarteko Telekomunikazio Elkartetik (ITU), http://emfguide.itu.int/emfguide.html

Gaur egun EEI-EEMen arriskua agerian uzten duten bi mekanismo baizik ez daude aho batez onartuak. ELFen kasuan, nerbio-sistema eta muskulu-ehunak estimulatuko lituzkeen eremu eta korronte elektrikoen indukzioa litzateke onartutako mekanismoa; irradiatutako energiaren absortzioa izango litzateke IMen kasuan, eta ondorio gisa gorputz-tenperaturaren gorakada gertatuko litzateke. Maiztasun txikien barneratze-sakonera handiagoa da ehunetan, maiztasun handiagokoekin alderatuz. Sakonera honek zehaztuko du osasunean kalteak eragin ditzaketen aldaketa biologikoak eragiteko duten gaitasuna. Hala ere, mekanismo hauek intentsitate altuaren ondorioz sortutako efektu akutuan oinarritzen dira, baina gaur egungo kezka, aldiz, esposizio maila baxuen pean sor daitezkeen efektu kronikoak dira.

ZER IKERTU DA ETA ZER DAKIGU ORAIN ARTE?

Efektuei buruzko ikerketa hiru alorretan egiten da:

1. Ikerketa batzuek *in vitro* aztertzen dituzte material biologikoetan eta batez ere zelula prokariota zein eukariotetan gertatzen diren kalteak.
2. Ikerketa batzuek *in vivo* aztertzen dituzte bizidunetan eta batez ere karraskarietan gertatutakoak.
3. Ikerketa epidemiologikoek, populazio jakin bat hartzen dute aztergai.

Ikerketa mota oro eduki behar da kontuan arriskuen balorazio bat egiterako orduan [14].

1. *In vitro* ikerketak

In vitro ikerketak funtsezkoak dira. Izan ere, ezinbestekoak dira osasunean eragindako efektu baten mekanismo biologikoak ezagutzeko. Korronte elektrikoen indukzioaz eta efektu termikoaz gain, orain arte ez da deskribatu komunitate zientifiko osoak onarturiko efektuen eragile izan daitekeen beste mekanismorik.

1.1. *Efektu neoplasikoak*

Genotoxizitatea aztertzen duten ikerketek EEI-EEMek kalte genetikoak sortzeko duten gaitasuna aztertzen dute. Material genetikoan eragindako aldaketak, potentzial kartzinogenoaren edota herentziazko gaixotasunen adierazgarriak dira egonkorrak direnean eta belaunaldi batetik bestera igaro daitezkeenean. ELFen kasuan, eremu magnetikoaren intentsitatea 1 mT-tik, eta kasu batzuetan 100 µT-tik gorakoa izan denean, efektu genotoxikoak aurkitu dira Osasunerako Arrisku Emergenteen Zientzia Batzordeak (SCENIHR) egindako azterketa bibliografikoaren eta Vijalaxmi eta Prihodak egindako meta-analisiaren arabera [13,15]. Munduko Osasun Erakundearen (MOE) monografikoaren esanetan, ELFen efektu genotoxikoak ikusi ahal izan dira hainbat ikerketatan 50 mT-etatik gorako egonaldietan, DNAren zatitzea, kromosomen ezegonkortasuna eta gene-adierazpenaren aldaketak kasu [16]. Beste ikertzaile batzuek iradokitzen dute zeharkako efektu genotoxikoa gerta litekeela seinale-transdukzioaren modulazioaren bidez. Ondorioz, aldaketak eragingo lirateke zelula barneko kaltzio mailaren, proteinen fosforilazioaren edo entzima-aktibazioan [17]. Orain arte, ordea, ez da aurkitu ebidentzia nahikorik eta trinkorik IMen genotoxizitateari dagokionean. Efektuak aurkitu direnean DNA kateen apurketarekin edo ardatz akromatikoaren asaldurekin loturik egon dira. Badirudi efektuak aztertutako zelularen eta EEMen peko eraginaren ezaugarrien arabera gertatzen direla [18–20]. Jadanik proposatuta daude IMen genotoxizitaterako mekanismoak hala nola, efektu termikoak, erradikal askeak eta DNAren konponketa prozesuen aldaketak [21]. SCENIHRek 2015ean aztertu zituen genotoxizitatearen inguruko 31 artikulu, eta haien artean 13 ikerketek (% 42) efekturen bat aurkitu zuten [13]. Dena den, askotan gertatu izan dira genotoxizitate efektu hauek errepikatzeko arazoak [22], batez ere artikuluetan esposizioan eragin dezaketen hainbat aldagairen informazio osatua ez ematearekin zerikusia dutenak. Funtsezko aldagaiak dira esposizioaren intentsitatea, denbora eta konbinazio desberdinak, frekuentzien inguruko informazioa eta esposizioa sortzen duen sistemaren baldintzak eta artikuluetan argitaratu beharko lirateke [23]. Genotoxizitateaz gain, kartzinogenesia eragin dezaketen beste prozesu batzuk ikertu dira. Adibidez, apoptosia, oxidazio-estresa, eta zelula-proliferazioa, zelula-zikloa eta gene-adierazpenaren aldaketak. ELFen kasuan 100 µT intentsitatetik gora zelulen proliferazioaren gorakada ikusi da [24]. IMei dagokienez, mota honetako asaldura batzuk ikusi dira [25–27] baina ikerketa gehienek ez dute efekturik aurkitu. Abian jarri da era berean beste ikerketa-lerro bat, IMek beste agente genotoxiko batzuen eragina handitu ote dezaketen finkatzeko; era guztietako efektuak lortu dira, bai onuragarria [28], bai kontrako efektua bai eta efektu eza [29].

1.2. *Efektuak nerbio-sisteman*

ELFen kasuan ez dago efektu posibleen inguruko inolako ondoriorik ateratzeko euskarririk**.** Hala ere, zelulen diferentziazioan efektu positiboak ikusi dira [30,31]. Nerbio-sistemaren gaineko efektuak aztertzen dituzten ikerketek esposizio akutura mugatzen dute saioa, eta zelula mota bakarra erabiltzen dute. Gainera, ez dute modelo egokirik batez ere ELFekin zerikusia duten neuroendakatze-efektuak aztertzeko. Horrek guztiak eragozpenak eragiten dizkio metodologia honi. IMen kasuan, neurotoxikotasuna aztergai duen *in vitro* ikerketa gutxi daude. Mikroglia edota astrozitoen aktibazioa aztertzea da ikerketa hauen helburu nagusia. Izan ere, homeostasi-erradikalean aldaketak eta ondorioz zelulen estresa dakar aktibazio horrek. Egile batzuek mikrogliaren aktibazioa ikusi ahal izan dute [32,33], baina hala ere ebidentziak ez dira oraingoz behar bezain zorrotzak.

2. ***In vivo* ikerketak**

In vitro ikerketekin alderatuz, *in vivo* ikerketek abantaila garrantzitsua daukate aintzat hartzen baitute toxikozinetika eta toxikodinamika prozesuak. Prozesu hauek, organismoa osatzen duten osagai guztien eta kutsatzaile edota agente kaltegarrien arteko interakzioa behatzen dute. Hala ere, *in vivo* ikerketen bidez lortzen diren emaitzak ezin dira zuzenean gizakietara estrapolatu eta ikerketa epidemiologikoekin berretsi behar dira.

2.1. *Efektu neoplasikoak*

Karraskarietan eginiko ikerketa gehienek ez dute arrazoirik eman EEI-EEMek eragin minbizi-sortzailea dutela pentsatzeko. IARC minbiziaren ikerkuntzarako nazioarteko agentziaren esanetan, ebidentzia mugatua da. Izan ere, asko dago hobetzeko efektu batzuk ikusi dituzten ikerketa batzuen diseinuaren eta datu-interpretazioaren aldetik. Halaber, ELFei dagokienez haurren leuzemia eta, batez ere, leuzemia linfoblastiko akutua ikertzeko animali modelo egokien gabezia dago. IMei dagokienez gehienek emaitza negatiboak lortzen dituzte, salbuespenak salbuespen [34]. Esaterako, Bartsch et al.-ek (2010) epe-luzeko eta intentsitate baxuko GSM pean ez zuten aldaketarik antzeman hainbat tumoretan, baina bai bizialdiaren luzeran, murriztapena gertatu zelako azken horretan [35].

2.2. *Efektuak nerbio-sisteman*

Ikerketa batzuek arazoak ikusi dituzte nerbio-sisteman. Besteak beste, oroimenean eta ikaskuntzan behatu dira aldaketak [36–38], bai ELF eta bai IMen peko egonaldietan. ELFen kasuan antsietatea eragin dutela ikusi da [39]. Dena den, emaitzek ez dute beharrezko sendotasunik eta ezin daiteke gizakiengan efekturik ondorioztatu. Neurogenesia, zitotoxizitea eta garunaren endekapena bezalako efektuak ikusi dira, beti ere intentsitate maila gomendagarrietatik oso gora [13].

2.3. *Efektuak ugalketan*

Ugalketa aztertu duten ikerketek efektuak antzeman dituzte bai ugalkortasunean, bai eta ondorengoen garapenean.

ELFei dagokienez, batez ere ikerketa epidemiologikoak egin dira, baina badaude *in vivo* ikerketak egin dituzten egileak. Esaterako, saguen organo genitaletan, bereziki testikuluetan asaldurak [40] eta itsas trikuen ondorengoen garapenean arazoak, zehazki mitosi prozesuko ziklo-zelularraren lehenengo fasean asaldurak eraginez [41], behatu dituzte.

IMen ustezko efektuak era askotarikoak dira: besteak beste, folikuluen murrizketa eta obozitoen DNAn kalteak, apoptosiaren eta endometrioko oxidazio-estresaren areagotzea, testosteronaren murrizketa, espermatogenesiaren asaldurak, espermako kalte genetikoa, oxigeno espezie erreaktiboak, erradikal askeak, peroxidazio lipidikoa eta glutation peroxidasa eta superoxidodismutasa entzimen murrizketa barrabiletan [42,43].

Ikerketa ugaritan ikusi ahal izan dira IMeko uhinek eragiten dituzten efektu teratogenikoak, baina beti ere esposizio maila tenperaturaren gorakada nabarmena eragiteko gai denean (gradu zentigradu bat baino gehiagoko gorakada). Haatik, ez da efektu hau egiaztatu legislatutakoa baino intentsitate maila baxuagoetan [13]. Honetaz gain, emaitza positiboak dituzten ikerketa askok lagin tamaina txikia edota metodologia-mugak dituzte.

3. **Ikerketa epidemiologikoak**

Ikerketa epidemiologikoak funtsezko tresna dira toxiko izan daitekeen edozein agente eta osasunean gerta daitezkeen ondorioen artean harreman bat ikusteko, interpretatzeko eta arriskuen ebaluazioa egiteko.

3.1. *Efektu neoplasikoak*

IARC minbiziaren ikerkuntzarako nazioarteko agentziak, 2B kategorian sartu zituen ELFak 2002an, umeengan leuzemia kasuen areagotzearekin behatu zituzten erlazioen ondorioz. Wertheimer eta Leeperrena izan zen umeengan gertatutako leuzemia kasuak eta ELF uztartu zituen lehenengo ikerketa 1979an [44]. Tentsio altuko lineetatik hurbil bizi ziren umeek leuzemia garatzeko arrisku bikoitza zutela behatu zuten. Esposizioa estimatzeko era, ordea, metodo ez-zuzenetan oinarritu zen, tentsio altuetatik dagoen distantzia eta sare elektrikoaren konfigurazioa kontuan hartuz eta neurketa zuzenik egin gabe. Ondorengo ikerketetan, batez ere, 0.3 eta 0.4 µT-ko intentsitatekoak dira umeen leuzemia linfoblastiko akutuarekin behin eta berriro [45–47] erlazionatu diren esposizio mailak. MOEaren prentsa-ohar batean, kalitatezko ikerketetan etxeetan dagoen maiztasun industrialeko (50 Hz) 0.4 µT-latik gorako eremu magnetikoa eta umeen leuzemiaren arteko asoziazio estatistikoa behatu zela adierazi zen [48]. Ikuspegi epidemiologikotik, ondorioztatu da minbizi-eragile izan litezkeela, harremana nahiko sendoa dela baitirudi. Hala ere, ezezagunak dira parte hartzen duten mekanismoak, eta animalia-ereduek ez diote efektu neoplasikoari eusten. Talde honen baitan egoteak leuzemia kasuek gora egitea gerta daitekeela esan nahi du eta beraz, azpimarratzen da sakonago aztertu behar direla bai esposizioa, bai eta efektuak ere.

IARCek IMak ere 2B kategoriaren baitan sartu zituen 2011n, gizakiarentzat minbizi-eragile izan daitezkeela ondorioztatu ostean. Erabakia hartzeko, sakelako telefonoaren erabilerarekin lotutako glioma kasuen hazkundean oinarritu ziren. Gizakietan frogak mugatuak direlako eta ikerketarako animalietan froga eskasak daudelako sartu zen kategoria horretan. Kontrol kasurako egin den INTERPHONE izenekoa da ikerketa epidemiologiko ezagunena. Ondorio gisa, sakelako telefonoaren erabileran ordu gehien pilatuta zituztenen artean (1640 ordu baino gehiago) soilik ikusi zen gliomaren arriskuaren handitzea, baina ez zen dosi-efektu gisako erantzunik aurkitu [49]. Hardell et al.-ek (2011) buruko tumore kaltegarrien kasuen gorakada ikusi zuten hari gabeko telefonoa eta sakelako telefonoa hitz egiteko gehien erabiltzen zutenen artean. Izan ere, ikusi zuten arriskua goraka zihoala latentzia-denbora eta erabilera handitu ahala [50]. Schuz et al.-ek (2006), aldiz, ez zuten tumore arriskurik aurkitu, sakelako telefonoen erabiltzaileak 7 eta 10 urte bitartean jarraitu ostean [51]. Dena den, Bann et al.-ek IARCen izenean, sakelako telefonoen erabiltzaileen sailkapen desegokia egin zutela esan zuten, mugikorren harpidedun guztiak erabiltzaile gisa kontsideratu baitzituzten, benetako erabilera kontuan izan gabe [52].

Nagusiki, bi ikerketak aztertu dituzte umeen eta nerabeen garuneko minbiziak. Kasu kontrolekoa den CEFALO ikerketak ez zuen harremanik aurkitu garuneko tumorea zuten 7 eta 19 urte arteko gazteen eta sakelako telefonoaren erabileraren artean (galdetegi bidez eta ahal zenean operadoreen bidez jasotako informazioa). Bestalde, abian da kasu kontroleko MOBIKIDS ikerketa eta bertan kontuan hartu dira garuneko tumorea duten 10 eta 24 urte arteko 1.000 gazte, eta kontrol gisa jardungo duten beste horrenbeste gazte [53].

Era berean ikergai izan dira sakelako telefono, irrati eta telebista-antenek gorputz osoan eragiten duten esposizioak dituen efektuak ere. Esposizio maila estimatzeko, ikertzaile askok iturrira dagoen distantzia hartu dute aintzat. Dode et al.-ek (2011) [54] korrelazioa ikusi zuten minbiziaren ondoriozko hilkortasuna eta telefono-antenekiko distantziaren artean. Gainera, hilkortasun tasa handiagoak ikusi ziren 500 metroko distantzietan. Beste egile batzuek antzeko emaitzak behatu zituzten [55,56]. Hala ere, ikerketa guztiek ez dute erlaziorik aurkitzen [57]. Askok, gainera, esposizioa estimatzeko erradiazioaren iturrira dagoen distantzia erabiltzea kritikatzen dute, distantzia eta intentsitate-mailen arteko asoziazio baxua erakutsiz. Distantziaz gain, aldagai ugari hartu beharko lirateke kontuan, emisio-iturriaren altuera, kokapena, orientazioa, maiztasunak eta lekuko geometria espaziala kasu [58].

3.2. *Nerbio-sisteman eta jokabidean efektuak*

Populazio helduari dagokionez, industria-maiztasunen (50 Hz) egonaldia pairatzen duten langileetan ikusi da gora egin duela neuroendekapen gaixotasun batzuk jasateko arriskuak. Alboko esklerosi amiotrofikoa (hots, neurona motorearen gaixotasuna) da gaixotasun horietako adibide bat [59,60]. Ikerketa suitzar bat izan zen tentsio altuko lineek eragindako ELFen peko eta neuroendekapen gaixotasunen arteko lotura antzeman zuen lehenengoa. Horrela, Huss et al.-ek (2009) ikusi zuten Alzheimerra eta zahartzaroko dementzia garatzeko arriskua handiagotzen zela denbora luzez tentsio altuko lineetatik 50 metro baino gutxiagotara bizi izan zirenengan [61]. Hala ere, Danimarkako populazioa ikertu zuen kontrol-kasuko ikerketa batek ez zuen harremanik aurkitu tentsio altuko lineetatik 50 metro baino gutxiagotara bizitzea eta Alzheimerra, dementzia, Parkinsona, esklerosi anizkoitza edo alboko esklerosi amiotrofikoa bezalako gaixotasunak garatzearen artean [62].

IMei dagokienez esposizio akutua eragin zaien boluntarioetan, begiratu da nerbio-sistemaren funtzio espezifikoetan aldaketak gertatu ote diren. Esate baterako, gertutik aztertu dira kognizio-funtzio batzuk, hala nola loaldiko burmuin-jarduera, psikomotrizitatearen arazoak, zentzumen ahalmenak eta oroimena, atentzio eta kontzentrazioa. Ikusi da IMek gaitasuna dutela elektroentzefalogramaren patroi normala [63], loaldiaren estadioak eta funtzio kognitiboaren aldaketak eragiteko, baina hala ere, beste ikerketa batzuek ez dute hori egiaztatu eta kasu batzuetan egile berberek baldintza berdinetan ikerketa errepikatuz ezin izan dituzte emaitzak egiaztatu [64].

Urriak dira IMek ume eta nerabeen kognizio-funtzioetan sortzen dituzten arazoei buruzko ikerketak. Umeen garuna guztiz osatu gabe dago eta batzuen ustez efektu neurofisiologikoei dagokienez sentikorragoak izan daitezke garapen-fase honetako garunak [65], baina kontua eztabaidagai da oraindik ere [66]. Batez ere hiritarrek erabiltzen dituzten sakelako telefonoek sorturiko esposizioa izaten da soilik aintzat hartutako IM iturria. Ikerketa batzuek jaio aurretiko esposizioa baizik ez dute kontuan hartzen. Alegia, amak haurdunaldian egindako sakelako telefonoaren erabileraren arabera egin dute azterketa, eta beste batzuek aldiz, umeak berak jaio ostean egindako erabilera hartzen dute esposizio iturri gisa. Guxens et al. (2013) [67] eta Vrihjeid et al.-ek (2010) [68] egindako lanak dira lehenengokoen artean ezagunenak. Ez zuten efekturik aurkitu baina esposizioaren estimazioaren kalitate baxua salatu izan da. Lehenengo lanaren kasuan amei atzera begira galdetegi bidez galdetu zitzaien umeek 5 urte zituzten garaiari buruz, eta bigarren kasuan, haurdunaldian egindako deien maiztasuna galdetu zitzaien, erabilera-denbora kontuan hartu gabe. Esposizioaren estimaziorako umeek edo nerabeek egindako mugikorraren erabilera kontsideratu duten ikerketek, prozesu kognitiboen ebaluazioan efektu laguntzailea [69,70] edo efektu gabezia [71–73] ikusi zuten batzuek. Bestalde, ikertzaile talde berak birritan ikusi zituen portaera-arazoak lagin handia erabili zuen ikerketa batean [74,75]. Australiako zeharkako MoRPhEUS ikerketak, aldiz, efektu onuragarria behatu zuen, sakelako telefonoa gehien erabiltzen zuten nerabeek erantzun-denbora motzagoa baitzuten, nahiz eta zehaztasun okerragoa izan [76]. IMen kognizio-efektuen inguruan egin diren ikerketek orokorrean esposizio akutua eta epe motzera neurtzen dituzte efektuak eta, beraz, epe luzera eragiten duten efektuetan sakondu egin beharko litzateke.

3.3. *Efektuak ugalketan*

Ugalketan, antzutasunean, berezko abortuetan eta sortzetiko gaixotasunetan ELFek eragin ditzaketen efektuak aztertu izan dira, batez ere lan jardueraren ondorioz esposizioa jasan duten gizakiengan. Orokorrean, emaitzek ez dute ugalketan arriskurik behatzen normalean gertatzen diren esposizio mailetan, bai ingurumen jatorriko bai lan jardueraren jatorriko ohiko intentsitateetan. Esposizio altua pairatzen dutenengan, ordea, arriskuaren handitze bat ikusi da [77].

Esperma IMekiko kaltebera izan daitekeelako hipotesia ere jorratu izan da. Gutschi et al.-en (2011) ikerketan, antzutasun-klinika bateko 2.100 pazienteren semena analizatu zen 1993 eta 2007 urteen artean [78]. Ikertzaileek ikusi zuten semenaren mugikortasun eta morfologia-kalitate okerragoa zutela sakelako telefonoa erabiltzen zutela zioten gizonezkoek. Hala ere, ikerketa honek ez zituen kontuan hartu IMen iturri izan zitezkeen beste batzuk, ez eta antzutasunean eragin zezaketen beste aldagai batzuk. SCENIHRen arabera, ez dago ebidentzia nahikorik IMek gizonezkoen ugalkortasunean eragiten dutela esateko [13].

3.4. *Sintoma ezespezifikoak*

Ondoeza orokorra, buruko mina edo lo egiteko arazoak bezalako sintomak behatu izan dira EEMekin harremanetan [79,80]. Dena den, ikerketa gehienek antenetatiko edota tentsio altuko lineetatiko distantzia erabili dute esposizioa estimatzeko erreferentzia modura. Gainera, pazienteen subjektibotasuna arazo izan daiteke, sintomak neurtzeko zailtasuna dela eta. Horrela, parte-hartzaileek eurek esandakoaz fidatzea besterik ez da geratzen. Porsius et al.-ek (2015) aurkitu zuten tentsio altuko lineetatik gertu (300 metrora) bizi ziren biztanleek sintoma gehiago erakusten zituztela, nahiz eta linea horiek oraindik funtzionamenduan ez egon [81]. Bortkiewicz et al.-ek (2012) ere hurbiltasuna eta aitortutako sintomen arteko harremana ikusi zuten IMen kasuan [80].

Azken urteotan, osasun publikoaren baitan sonatua egin da EEMekiko hipersentikortasuna deritzona. Sintoma ezberdin eta ezespezifikoak edukitzean datza hipersentikortasun hori: buruko minak, letargia, loaldian asaldurak, antsietatea...

Hainbat ikerketatan argi ikusi da ez dagoela benetako loturatik benetako esposizioa, hots, neurtutakoa eta parte-hartzaileek esandako sintomen artean [13,82].

EEMen EFEKTUEN INGURUKO EZTABAIDA

Ikerketa ugari egin dira, baina hala ere, kontu honetan zalantza ugari daude, batez ere metodologiak dituen mugengatik. Gehienetan ikerketen emaitzak ez dira errepikatuak, ez dira sendoak edota ez dute dosi-erantzun gisako ondoriorik izaten.

Ugariak izan daitezke ikerketetan gertatutako sendotasun ezaren arrazoiak: besteak beste, metodologia-mugak, diseinu esperimental desberdinen aniztasuna, esposizio-denbora laburra, lagin txikiaren ondorioz duten esangura estatistiko baxua, efektuak neurtzeko erabilitako test desberdinen aniztasuna, beharrezko latentzia-denbora aintzat ez hartzea, kontuan hartu gabeko aldagai nahasgarriak eta sintomen berri emateko unean egon daitezkeen subjektibotasun arazoak izan daitezke [13,83].

EEI-EEMen efektuak oraindik eztabaidagai daude besteak beste egonaldiaren estimazio desegokia edo osagatugabea egin omen delako. Izan ere, normalean, ikerketek ez dituzte EEI-EEMak sortzen dituzten iturri guztiak kontuan hartzen eta metodo zuzenak posible ez direnean halamoduzko estimazioa egiten duten metodo ez-zuzenak erabiltzen dituzte [84].

ZIENTZIA-IKERKETAREN ORAINGO EGOERA

Estatu(en) arteko mailan MOEk CEM proiektua (http://www.who.int/peh-emf/project) abiarazi zuen 1996an eremu elektriko eta magnetikoek ingurumenean eta osasunean eragiten dituzten efektuak aztertzeko. Europako hainbat egitasmok diru-laguntzak jaso dituzte, EEI-EEMen efektu eta ekintza-mekanismoak aztertzeko. Batez ere, *in vitro* eta *in vivo* saioak egin dituzte esaterako REFLEX edo CEMFEC bezalako proiektu sonatuek (http:// ec.europa.eu/health/ph_determinants/environment/EMF/brochure_en.pdf). Ikerketa hauek guztiek ez dute emaitza argirik eman.

EEI-EEMen iturri diren teknologien erabilerak gora egin du eta emaitza kontraesankorrak lortu dira. Beraz, jarraitu egin beharko genuke epe luzera batez ere umeetan gerta daitezkeen efektuak ikertzen. Hori dela eta, Bruselan izan zen EEI-EEMei buruzko estatu arteko batzarrean kohorte-ikerketa epidemiologikoak eta protokolo zehatzak gauzatzeko beharra nabarmendu zuten gaian adituak direnek. Une honetan, abian daude IMen efektuak aztertzen dituzten hainbat ikerketa epidemiologiko; lehenik kontrol-kasuko MOBI-Kids ikerketa [53], bigarrenik, 250.000 heldu baino gehiago 25 urtetan zehar jarraituko dituen COSMOS (Cohort Study of Mobile phOne uSe and health) [85] ikerketa, minbiziak, tumore onberak, buruko minak, loaren kalitatea eta ongizate orokorra aztertuz. Hirugarrenik, HERMES (Health Effects Related to Mobile phonE use in adolescentS) kohortea [86] eta azkenik GERoNiMO proiektua (Generalised EMF Research using Novel Methods- an integrated approach: from research to risk assessment and support to risk management) (http://www.crealradiation.com) EEI-EEMek dituzten efektuak era ezberdinetan (*in vitro*, *in vivo* eta ikerketa epidemiologikoekin) baloratzen dituena.

Gipuzkoan, INMA (*INfancia y Medio Ambiente- Ingurumena eta Haurtzaroa*; www.proyectoinma.org) proiektuak kohorte bat du eta parte hartzen du GERoNiMO proiektu Europarraren ikerketa lerro batean. Zehazki, IMek umeen neurogarapenean duten eragina epidemiologiaren aldetik aztertzen da [84]. INMA proiektuaren barruan nagusiki zehaztu nahi dute zein efektu eragiten dituen umeen garapenean, haurdunaldian eta bizialdiko lehenengo urteetan ingurumen kutsatzaileen peko egonaldiak. Egun, Espainia mailan 6 kohortek diraute eta Gipuzkoakoa da berriena, aztergai diren 450 inguru umeek 8 urte dituztelarik. Neurogarapenari dagokionez, berriki abian jarri da gazteak aztergai dituen SCAMP izeneko proiektua [87]. ELFei dagokienez aldiz, orain arte metodo ez-zuzenen bidez eta iturri guztiak kontuan izan gabe egin da esposizioaren karakterizazioa, baina azkenaldian, ohikoagoak dira iturri guztiak aintzat hartzen dituzten ikerketak, eta esposizioa neurketa zuzenen bidez [88] edota neurgailu pertsonalen bidez estimatzen da.

ONDORIOAK

Organismo ofizialek, estatu mailakoek zein estatu artekoek, uste dute egungo ebidentzia mugatua dela eta ezin ondoriozta daitekeela EEI-EEMen eta efektuen arteko kausa/efektu harremana dagoenik, beti ere esposizio mailak gomendio eta araudien azpitik daudenean [13,89–91]. Dena den, azpimarratu dute metodologiako arazoei aurre egiten dieten ikerketa sendoak egiteko beharra dagoela. Eginbidean dauden proiektuek gaia argitzen lagundu bitartean, funtsezkoa da herritarren ardurei erantzuteko nazio arteko erantzun koordinatu bat.

ESKER ONAK

MGk eskerrak eman nahi dizkio Hezkuntza, Hizkuntza politika eta Kultura sailari, doktore tesia egiteko jaso duen diru-laguntzagatik.

1.3. Telefonia mugikorraren antenak: kokapena eta inguru sentikorrekiko gertutasuna INMA-Gipuzkoa ikerketa-eremuan

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Ondorengo izenburuarekin argitaratua: [Antenas de telefonía móvil : emplazamiento y proximidad a espacios sensibles en la zona de estudio Inma-Gipuzkoa]

Revista de salud ambiental 2014; 14(2):98-106

LABURPENA

Europan, 1999/519/EC Gomendioak ezartzen ditu jendarte orokorrarentzat eremu elektromagnetikoen (0 Hz –300 GHz) esposizioaren mugak eta erreferentzia mailak. Herrialde ugarik, Espainiak barne, “inguru sentikor” deritzenetan esposizioaren iraupenaren eta biztanleria sentikorraren presentziaren araberako muga murriztaileagoak eta neurri gehigarriak ezarri dituzte.

Ikerketa honen helburua INMA-Gipuzkoa proiektuko herrietan telefonia mugikorraren antenen kokapena eta gune sentikorrekiko gertutasuna zehaztea da. Horretarako antenak eta eremu sentikorrak (eskolak, osasun-zentroak, zahar-egoitzak eta parke publikoak) geoerreferentziatu ziren. Eragin-eremuak inguru sentikorrekiko distantziaren arabera (50, 100, 300 eta 600 m) sailkatu ziren eta eremu bakoitzeko telefonia mugikorraren antena kopuruak zehaztu ziren.

247 inguru sentikor eta 156 antena zenbatu ziren guztira. Antenen % 54a zehaztutako eragin-eremuen barruan aurkitu ziren. Osasun-zentro batean eta parke batean salbu, gainerako inguru sentikorretan ez zen antenarik aurkitu 100 m-ko erradioan. Inguru sentikorren % 46k 600 m-ko erradioaren barruan gutxienez antena bat zutela ikusi zen, % 20.6ak 1 eta 3 antena bitartean, % 21.5ak 3 eta 6 antena bitartean eta gainontzeko % 4.9k 6tik gora antena zituztelarik.

Bi inguru sentikorretan soilik aurkitzen da antena bat gertuko eragin-eremuan (0-100 m). Dena den, distantzia ez da esposizioan eragiten duen aldagai bakarra, eta ondorioz beharrezkoa litzateke etorkizuneko ikerketek inguru hauetako esposizio-mailak neurtzea.

Hitz-gakoak: eremu elektromagnetikoak; irrati-maiztasuna; telefonia mugikorra; analisi espaziala; biztanleria sentikorra.

SARRERA

Erradiazio ez-ionizazaileko eremu elektromagnetikoak (EEI-EEM) geroz eta ohikoagoak dira gure inguruan, eta hauek epe luzera izan ditzaketen eraginek biztanlerian sortzen duten kezka ere haziz doa. 90. hamarkadan telefono mugikorrak agertu zirenetik, etengabeko igoera azkar eta orokortu bat jazo da telefonia mugikorraren antena kopuruan [92]. Europako batzordeak 2010. urtean biztanleriari luzatutako azken inkestaren arabera, goi-tentsioko lineen ostean, telefonia mugikorraren antenak dira biztanlerian kezka gehien sortarazten duten EEI-EEM-en iturriak. Inkesta erantzun zuten europarren % 70ak eta espainiarren kasuan % 75ak uste du, telefonia mugikorraren antenek osasunean nolabaiteko eragina dutela [93].

Europan babes erradioelektrikoaren inguruko esparru legala 1999/519/EC Gomendioak zehazten du, eta bertan ezartzen dira jendarte orokorrarentzat EEI-EEM-ekiko esposizioaren oinarrizko mugak eta erreferentzia mailak [94]. Azken hauek onartutako gehienezko EEI-EEM esposizio mailak zeintzuk diren adierazten dituzte. Europar batzordearen Gomendio hau erradiazio ez-ionizatzaileen babeserako nazioarteko batzordearen (ingeleseko siglak: ICNIRP, *International Commission on Non-Ionizing Radiation Protection*) gidalerroetan oinarritzen da [95]. Telefonia mugikorrak lan egiten duen maiztasunentzat erreferentzia maila ezberdinak ezartzen dira potentzia-dentsitateari dagokionez. 900 eta 2000 MHz arteko maiztasunentzat erreferentzia maila maiztasuna zati 200 eginda kalkulatzen da (f/200), gaindi ezin daitekeen balio altuena 4,5 W/m^2 delarik 900 MHz maiztasunarentzat. 2000 eta 2600 MHz arteko maiztasunentzat, aldiz, erreferentzia maila 10 W/m^2 baliora mugatzen da. Europar Batasuneko estatu kideen gehiengoak gomendio hauek bere egin ditu, eta are gehiago, kide batzuk muga murriztaileagoak edota neurri gehigarriak ezarri dituzte. Kasu batzuetan muga murriztaileago hauek "inguru sentikor" deritzonetan soilik ezartzen dira, esposizioaren iraupenaren eta hau jasango duen biztanleria motaren (ume, adineko, gaixo) arabera [96].

Espainian 1066/2001 Errege Dekretuak arautzen ditu domeinu publiko erradioelektrikoaren zaintza, emisio erradioelektrikoen mugak eta hauen aurrean osasuna babesteko hartu beharreko neurriak. Dekretu honek europar gomendioak bere egiten ditu, muga eta erreferentzia maila berak ezarriz, baina era berean neurri gehigarriak ezartzen ditu inguru sentikorrak babesteko [97]. Hala, Errege dekretu honen 8. artikuluak eta CTE/23/2002 Aginduak haurtzaindegietatik, haur-eskoletatik, derrigorrezko hezkuntza zentroetatik, osasun zentroetatik, ospitaletatik, parke publikoetatik, zahar-egoitzetatik edo eguneko zentroetatik 100 m baino gutxiagora dauden estazio erradioelektrikoen operadoreak esposizioaren gutxitzea arrazoitzera behartzen ditu [97,98]. Estatu-mailako araudi hau izanik ere, Europar

Batzordeak 2010ean gauzatutako inkestaren arabera [93] espainiarrek hartu beharrekotzat ikusten zituzten hurrengo neurriak: biztanleriari informazio gehiago eskaintzea (% 56), segurtasunerako estandarrak ezartzea (% 36) eta biztanleria babesteko gidaliburuak sortzea (% 30).

Bi arazo nagusi aurkitzen dituzte agintariek biztanleriaren eskaera honi erantzuterako orduan, alde batetik EEI-EEM-ekiko esposizioak osasunean izan dezakeen eraginaren inguruko adostasun falta, eta bestetik, biztanleria orokorrak jasaten duen benetako esposizio mailei buruzko ezjakintasuna. Hori dela eta, beharrezkoa ikusten da esposizio maila hauek ezagutzeko neurketak egitea, modelizatzea eta esposizio mailak zehazten dituen mapak garatzea.

Gauzatutako ikerketa helburu hau betetzeko bidean egin den lehen urratsa da, eta INMA-Gipuzkoa proiektuko herrietan telefonia mugikorraren antena kopurua, euren kokapena eta gune sentikorrekiko gertutasuna zehazten ditu.

METODOLOGIA

Ikerketa esparrua

Ikerketa esparruak INMA (Infancia y Medio Ambiente, www.proyectoinma.org/) proiektuko partaideen herriak hartzen ditu bere baitan. 2006. urtean hasi zen ikerketa epidemiologiko prospektibo bat da INMA, 638 ama/seme-alaba bikotez osatua, ingurumen eragileekiko esposizio goiztiarrek haurren garapenean eta osasunean duten eragina ikertzen duena [11]. Ikerketa esparrua Gipuzkoako hegoaldean kokatzen da (1. Irudia), eta Goierriko eta Urola Garaiko eta Erdialdeko eskualdetako 23 herrik[1] osatzen dute, guztira 95.442 biztanlek, hain zuzen ere.

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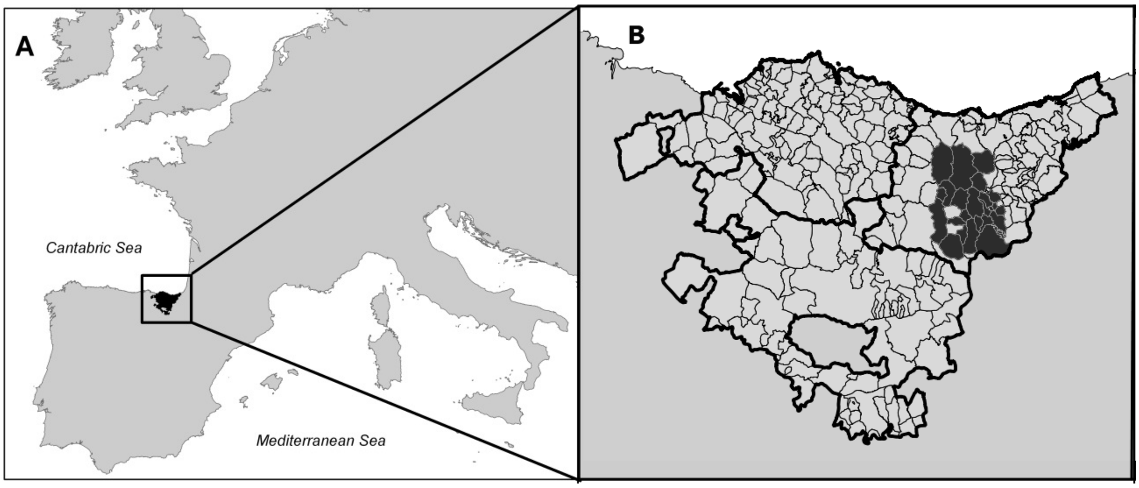
[1] 25 herrik osatzen dute berez, baina bi herritako umerik ez zen proiektuan sartu



1. irudia. (A) Ikerketa eremuaren kokapena Europan. (B) Ikerketa eremuaren kokapena Euskal Autonomia Erkidegoan (EAE) (gris iluna)

Telefonia mugikorraren antenen eta inguru sentikorren geoerreferentziazioa

Ikerketa esparruaren barne aurkitzen diren ondorengo inguru guztiak geoerreferentziatu ziren: parke publikoak, haurtzaindegiak, hezkuntza zentroak (haur, lehen eta bigarren hezkuntza), osasun zentroak (anbulatorioak, osasun zentroak, lehen mailako arretarako kontsultategiak, buruko osasunerako zentroak eta ospitaleak) eta adinekoen egoitzak eta eguneko zentroak. Ikerketa esparruko eta herri mugakideetako telefonia mugikorraren antenak ere geoerreferentziatu ziren.

Inguru sentikorren kopurua eta kokapena udaletxeen, Eusko Jaurlaritzako Osasun eta Hezkuntza departamentuen eta Gipuzkoako Foru Aldundiko Politika Sozialerako departamentuaren bidez lortu ziren. Telefonia mugikorreko antenen kokapena aldiz Industria, Energia eta Turismoko Ministerioaren ''Infoantenas'' (http://geoportal.minetur.gob.es/VCTEL/vcne.do) [99] aplikazioaren bidez erdietsi zen.

Eragin-eremuak edo "bufferrak"

Eragin-eremuak, ingelesez "buffers'' deiturikoak, funtsezko tresnak dira gertutasun analisia gauzatzerako orduan. Eragin-eremuen bidez, aztergai diren elementu geografikoetan diametro ezberdineko azalerak sortzen dira, izan puntuak, lerroak zein poligonoak [100].

Eragin-eremu hauek sortzeko, 100 eta 300 m-ko distantziak hartu ziren kontuan, inguru sentikorretan muga murriztaileak ezartzerako orduan araudi europar ezberdinetan ezartzen diren distantziak hauek baitira [96,98]. Hauek baino azalera murriztaileagoak eta nasaiagoak sartze aldera 50 eta 600 m-ko distantziak ere txertatu ziren. Eragin-eremuak inguru sentikorren inguruan sortu ziren, eta informazio geografikoa ArcGIS 10.22 eta Quantum Gis Desktop 2.2.0 programen bidez aztertu zen.

EMAITZAK

Ikerketa esparruak barne hartzen dituen 23 herrietan 156 telefonia mugikorreko antena eta 247 inguru sentikor identifikatu ziren guztira. Erabileraren arabera banatuz, inguruen % 61 parkeek eta plazek osatzen dute, % 23 eskolek, % 11 osasun zentroek eta % 5 adinekoen egoitzek eta eguneko zentroek (1. Taula). Identifikatutako 56 eskolen % 14 (8 eskola) soilik dira bigarren hezkuntzako zentroak, eta gainerakoak haur hezkuntza eta lehen hezkuntza barne hartzen dituzten zentroak edo haur hezkuntza soilik eskaintzen duten zentroak dira, 0 eta 6 urte arteko haurrak doazenak, ustezko biztanleria sentikorrena alegia.

1. Taula

Inguru sentikor eta telefonia mugikorreko antena kopurua INMA proiektuaren ikerketa-eremuan

Inguru sentikorra	**Kopurua**
Eskolak	**56**
Haur eta lehen hezkuntza (0-12 urte) (HLH)	48
Bigarren hezkuntza (12-16 urte) (BH)	8
Osasun zentroak	**27**
Adinekoen egoitzak	**13**
Ostatudun egoitzak	8
Eguneko zentroak	7
Parke eta plazak	**151**
Telefonia mugikorreko antenak	**156**

2. Taulak aztertutako eragin-eremuen barruan gutxienez telefonia mugikorreko antena bat duten inguru sentikorren kopuruak eta ehunekoak biltzen ditu. Osasun-zentro bat salbu, gainerako inguru sentikorretan ez zen antenarik aurkitu 50 m-ko erradioan. 50 eta 100 m-ko erradioaren barnean antenen presentzia zuen parke bat soilik aurkitu zen. 100 eta 300 m-ko tartean, bigarren hezkuntzako eskolen kasuan salbu, mota ezberdinetako inguru sentikorretan

gutxienez antena bat izatea orokortzen da. Aztertutako eragin-eremu guztiak kontuan hartuz, 14 osasun zentrok (% 51,9), 74 parkek eta plazak (% 49,0), 6 egoitzak (% 46,2) eta 20 eskolak (% 35,7) dute gutxienez antena bat 0 eta 600 m arteko erradioaren barnean.

2. Taula

Eragin-eremuen barruan gutxienez telefonia mugikorreko antena bat duten inguru sentikorren kopuruak eta ehunekoak

	Eskolak (n=54)		**Osasun zentroak (n= 27)**	**Adinekoen egoitzak (n=13)**	**Parke eta plazak (n=151)**
Distantzia (m)	**HLH**	**BH**			
0-50	-	-	1 (3,7)	-	-
50-100	-	-	-	-	1 (0,7)
100-300	2 (4,2)	-	5 (18,5)	1 (7,7)	16 (10,6)
300-600	17 (35,4)	4 (50,0)	10 (37,0)	6 (46,2)	65 (43,1)
Guztira 0-600[a]	18 (37,5)	4 (50,0)	14 (51,9)	6 (46,2)	74 (49,0)

HLH: Haur eta lehen hezkuntza; BH: Bigarren hezkuntza

Parentesi artean, inguru sentikor mota bakoitzaren totalarekiko kalkulatutako ehunekoak

[a] Inguru sentikor batzuk ilara ezberdinetan errepikatzen dira, eragin-eremu batean baino gehiagotan dituztelako antenak. Beraz, 0-600 m ilaran ageri diren balioak eta zutabeko kopuruen batuketak ez dute zertan bat egin behar

Inguru sentikorrak eragin-eremuen arabera aztertzerako orduan ageriko ezberdintasunak ikus daitezke antena kopuruan (3. Taula). 0 eta 50 m arteko tartean osasun zentro bat soilik dago telefonia mugikorreko antena baten eraginpean. 50 eta 100 m arteko eragin-eremuan parke bat aurkitzen da 4 antenarekin. 100 eta 300 m arteko tartean inguru sentikorrek 1 eta 6 antena artean dituzte. 300 m-tik aurrera da antena kopuru handiena pilatzen den tartea, non hezkuntza zentroetan eta parkeetan 7 eta 10 antena artean aurkitzen diren, eta baita 10 antenatik gora ere osasun zentro baten kasuan.

3. Taula

Inguru sentikorren kopuru eta ehunekoa eragin-eremu ezberdinetan dituzten antenen arabera

		Eskolak		**Osasun zentroak**	**Adinekoen egoitzak**	**Parke eta plazak**
Distantzia	**Antena kopurua**	**HLH**	**BH**			
0-50	**1-3**	-	-	1 (100,0)	-	-
50-100	**4-6**	-	-	-	-	1 (100,0)
100-300	**1-3**	1 (50,0)	-	3 (60,0)	1 (100,0)	7 (43,8)
	4-6	1 (50,0)	-	2 (40,0)	-	9 (56,2)
	7-10	-	-	-	-	-
	>10	-	-	-	-	-
300-600	**1-3**	6 (40,0)	2 (50,0)	5 (50,0)	4 (66,7)	34 (52,3)
	4-6	7 (46,7)	1 (25,0)	4 (40,0)	2 (33,3)	24 (36,9)
	7-10	2 (13,3)	1 (25,0)	-	-	7 (10,8)
	>10	-	-	1 (10,0)	-	-
Guztira 0-600[a]	**1-3**	6 (37,5)	2 (50,0)	6 (42,9)	4 (66,7)	33 (44,6)
	4-6	8 (50,0)	1 (25,0)	7 (50,0)	2 (33,3)	34 (46,0)
	7-10	2 (12,5)	1 (25,0)	-	-	7 (9,4)
	>10	-	-	1 (7,1)	-	-

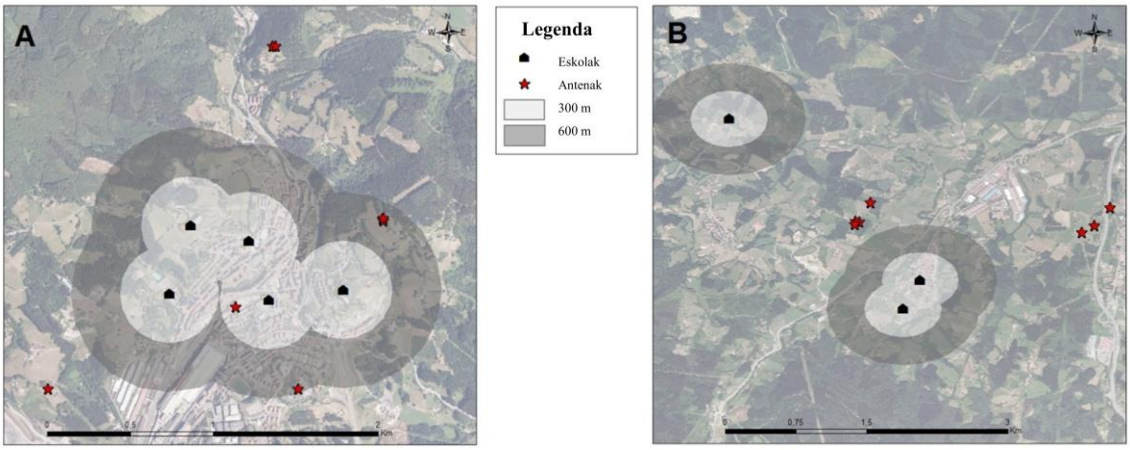
HLH: Haur eta lehen hezkuntza; BH: Bigarren hezkuntza

Parentesi artean, inguru sentikor mota bakoitzaren totalarekiko kalkulatutako ehunekoak

[a] Inguru sentikor batzuk ilara ezberdinetan errepikatzen dira, eragin-eremu batean baino gehiagotan dituztelako antenak. Beraz, 0-600 m ilaran ageri diren balioak eta zutabeko kopuruen batuketak ez dute zertan bat egin behar

Ikerketa esparruan identifikatutako 156 antenetatik 85 (% 54,5) aurkitzen dira inguru sentikorrentzat definitutako eragin-eremuen barnean. Gainerakoak inguru sentikorretatik 600 m baino gehiagora daude. 2. irudian eskolen kasuan 300 m eta 600 m arteko eragin-eremuetan aurkitzen diren antenen kokapena erakusten da adibide gisa. 50 eta 100 m arteko eragin-eremuak ez dira erakusten eskolen kasuan ez baitzen antenarik aurkitu buffer hauetan.

Antenak izar gorri baten bidez daude adierazita, baina antena batzuk kokapen bera partekatzen dutenez izar bakoitzak antena bat baino gehiago adierazi dezake. 2A irudian 300 eta 600 m artean antenak dituzten eskolak ageri dira. 2B irudian, aldiz, ageri diren hiru eskolek antenak 600 m baino gehiagora dituzte.



2. irudia. Eskolen kasuan 300 m eta 600 m arteko eragin-eremuetan aurkitzen diren antenen kokapena erakusten da adibide gisa.

Bestalde, herri mugakideetan kokatutako antena bakar bat ere ez da aurkitzen INMA-Gipuzkoa proiektuko herrietako inguru sentikorretatik 600 m baino hurbilagoko distantziara.

EZTABAIDA

Biztanleria babesteko irrati-maiztasunen emisioen aurrean hartu beharreko neurriei dagokienez, 1066/2001 Errege Dekretuak operadoreak normalean jendea egoten den lekuetan kokatutako antenen ondorioz sortutako esposizio mailen inguruko ikerketa zehatzak burutzera behartzen ditu. Bestalde, CTE/23/2002 Aginduak, neurri gehigarri gisa, antena inguru sentikorren batetik 100 m baino gutxiagora dagoenean gauzatutako ikerketan esposizio mailen murriztea zuzenestera behartzen ditu operadoreak [98]. Gure ikerketa esparruan 100 m-ko erradioaren barnean hurrenez hurren 1 eta 4 antena dituzten osasun zentro bat eta parke bat identifikatu dira. Beraz, 5 antena hauek soilik bete beharko lukete aipatutako Aginduaren neurri gehigarria. Europan, Frantzian, Danimarkan, Lituanian edo Erresuma Batuan kasu, antzerako neurri gehigarriak ezarri dituzte inguru sentikorrak babesteko, hala operadoreak esposizioa murriztera eta antenen kokapena elkarbanatzera behartuz [96]. Erresuma Batuan, eskolaren batetik hurbil antena bat ezarri nahi bada lehenik eta behin hezkuntza zentroari galdetzea beharrezkoa da [96].

Irrati-maiztasunen emisioen erreferentzia mailei dagokionez, Europar Batasuneko estatu kideen gehiengoak bere egin ditu 1999/519/EC Gomendioan ezarritako mailak. Are gehiago, estatu batzuek muga murriztaileagoak ezarri dituzte. Esaterako, Greziak, % 30 murriztu ditu muga hauek biztanleria orokorrarentzat, eta inguru sentikorretatik 300 m baino gutxiagora dauden antenen kasuan % 40. Bulgaria, Suitza eta Esloveniak aldiz biztanleria orokorrarentzat Gomendioko mailak bere egin dituzten arren, inguru sentikorren kasuan 10-100 aldiz muga murriztaileagoak ezarri dituzte [96]. Espainiako erkidegoei dagokionez, Gaztela-Mantxak [101] eta Nafarroak [102] muga murriztaileagoak ezarri dituzte biztanleria orokorrarentzat. Hala, Gaztela-Mantxan hirigunean onartzen den esposizio maila 10 $\mu W/cm^2$-ra mugatzen da telefonia mugikorreko maiztasun guztientzat, eta Nafarroan 2 W/m^2 eta 4 W/m^2 dira 900 eta 1800 MHz-etarako mugak hurrenez hurren. Are gehiago, Gaztela-Mantxan inguru sentikorren barruan kokatzen diren telefonia mugikorren zerbitzu bakoitzarentzat (GSM, DCS eta UMTS) ezartzen den potentzia-dentsitatearen muga 0,1 $\mu W/cm^2$-koa da. Beste erkidego batzuk erreferentzia mailak inguru sentikorren kasuan murriztu dituzte (Errioxa % 10, Gaztela eta Leon % 25 eta Nafarroa % 55) [102–104]. Gure kasuan, ikerketa esparruko antenen % 96,7 inguru sentikorretatik 100 m baino gehiagora aurkitzen dira, eta kasu hauetan ez dago esposizioa murriztera bideratua dagoen inongo neurririk edo mugarik, ez erkidego mailakorik ez estatu mailakorik.

Ikerketa askotan iturrira dagoen distantzia erabili izan da esposizio mailaren hurbilketa bat egiteko, eta hala osasunean izan ditzakeen eraginak balioesteko. Iturri gisa telefonia mugikorraren antena bat edo bat baino gehiago kokatzen diren estazioak hartu izan dira. Dode et al.-ek [54] telefonia mugikorren estazioekiko gertutasunaren eta minbiziak eragindako heriotza-tasaren artean korrelazio espaziala aurkitu zuten, estazioen biran 500 m-ko erradioko esparruan heriotza-tasa hau handiagoa zelarik. Wolf eta Wolf-ek [55] estazioetatik 350 m baino gutxiagora bizi direnetan minbizi mota guztientzat intzidentzia esanguratsuki altuagoa zela ikusi zuten. Eger et al.-ek ere estazioetatik 400 m baino gertuago bizi ziren pertsonek hortik kanpora bizi zirenekin alderatuz minbizia jasateko 3 aldiz arrisku handiagoa zutela ikusi zuten [56]. Dena den, beste ikerketa batzuek ez dute aurkitu loturarik minbizia izateko arriskuaren eta estazioekiko gertutasunaren artean [57]. Minbizia ez den beste osasun arazo batzuetan estazioekiko distantziak izan dezakeen eragina ere ikertua izan da, kasu batzuetan distantziaren eta sintoma ez espezifikoen (dermatologikoak, zorabioak, itolarria, nekea, digestio-nahasmenduak zein kontzentratzeko arazoak) artean erlazioa aurkituz [79,80,105]. Ikerlari askok estazioekiko distantzia esposizio mailaren hurbilketa egiteko aldagai gisa erabiltzea desegokia dela uste dute. Hala, egile batzuek erlazio baxua [106,107,108][2], aurkitu dute telefonia mugikorren estazioekiko distantziaren eta neurketa bidez erdietsitako esposizio balioen artean. Pollán et al.-ek erlazio baxu honen arrazoia erradiazioa blokeatu, difraktatu edo islatu dezaketen elementu fisikoak egotea dela iradokitzen dute [108]. Ondorioz, distantziaz gain beharrezkoa da esposizioa zenbatesterako orduan bertan aurki daitezken barrera fisikoak, eraikinak, zuhaitzak zein mendiak esaterako, kontuan hartzea.

Beste aldagai batzuk, antenaren noranzko bertikalak edo horizontalak (azimut eta downtilt), potentziak zein antena kokatzen den altuerak ere eragina izango dute esposizio mailetan. Beekhuizen et al.-ek zenbait aldagairen inguruko informazio faltak benetako esposizioa zenbatesterako orduan izan dezaketen eragina aztertu zuten [109]. Hala, esposizioa zenbatesterako orduan altueraren, kokapenaren, noranzkoaren, maiztasunaren eta eraikuntzaren 3D modeloaren inguruko datuak eskura izatea beharrezkoa dela ondorioztatu zuten. Era berean, potentziaren, inklinazio bertikalaren eta antena motaren inguruko informazioa baliagarria dela, baina ez guztiz beharrezkoa ikusi zuten.

Esposizioa zenbateste aldera, esposizio-mailetan eragina duten aldagai ezberdinak kontuan hartuz, irrati-maiztasuneko uhinen propagazioa aurreikusteko modeloak garatu dira. Bürgi et al.-ek garatutako NISMap modelo geoespaziala [110] telefonia mugikorren antenetatik datozen eremu elektromagnetikoak modelizatzeko balioztatua izan da, baita arrakastaz erabilia ere Suitzan eta Herbeheretan [92], dosimetroen bidez neurturiko esposizio maila indibidualen eta modelo bidez kalkulatutakoen artean korrelazio ona erdietsiz.

Gauzatutako ikerketak dituen mugei dagokienez, azpimarratu nahi genuke, alde batetik ikerketa telefonia mugikorren antenak kokatzean soilik ardaztu dela, eta hauek ez dira biztanleriarentzat irrati-maiztasunen iturri bakarrak. Dena den, Joseph et al.-ek hirietako kanpoko ingurunean telefono mugikorrekin batera irrati-maiztasuneko eremu elektromagnetikoen (IM-EEM) iturri garrantzitsuena telefonia mugikorraren antenak zirela ikusi zuten [111]. Telefonia mugikorraren antenek, sakelakoen erabilerak ez bezala, urruneko eremuan jasotzen diren emisioak sortzen dituzte, gorputz osora esposizio jarraitu eta homogeneoa bideratuz. Gauzatutako ikerketaren beste muga bat inguru sentikorren geoerreferentziazioa burutzerako orduan hauek azaleratzat hartu beharrean puntutzat hartu direla da, ondorioz, azalera handiko inguru sentikorrek inguruan dituzten telefonia mugikorreko antenen kopurua gutxiestea gerta daitekeelarik. Aztertutako inguru sentikor gehienek azalera handia dutenez (batez ere parke publikoek), gerta daitekeen egoerarik

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[2] Argitaratutako artikuluan akatsa zegoen. Hemen era egokian jarri da.

okerrena behatu nahi bada, inguru hauek puntu beharrean azalera bezala kontuan hartzea beharrezkoa da.

Lan hau INMA-Gipuzkoa proiektuko esparruan IM-EEMekiko esposizioa karakterizatzeko eman den lehen urratsa da. Aurrerago gainerako iturriak identifikatuko dira, irrati eta telebista antenak esaterako, eta baita irrati-maiztasuna igortzen duten beste gailu batzuk ere. Hala, distantziaz gain erradiazioaren hedatzean eragina duten aldagai guztiak kontuan hartuko dira, eta zuzeneko neurketen eta modeloen bidez, irrati-maiztasunekiko esposizioaren hurbilpen bat lortuko da.

Erkidego mailan gaur artean ez da gauzatu telefonia mugikorreko antenen eta biztanleria sentikorra egoten den inguruneen geoerreferentziaziora bideratutako ikerketarik. Estatu mailan ikerketa bakarraren ezagutza daukagu, 2012. urtean Valentzian gauzatua, non telefonia mugikorren antenetatik 100 m baino gutxiagora aurkitzen ziren inguru sentikorrek IM-EEMekiko zuten esposizioa karakterizatu zen [112]. Ikerketa honetan, inguru sentikorretatik 100 m baino gutxiagora aurkitzen diren antenez gain, 100 eta 300 m artekoak eta 300 eta 600 m artekoak ere geoerreferentziatu dira. Bere mugak eduki arren, antenekiko distantzia oinarrizko aldagai bat da irrati-maiztasunekiko esposizioa kalkulatzerako orduan. Neitzke et al.-en arabera, antenekiko distantzia esposizio handiagoa edo txikiagoa izan dezaketen guneak identifikatzeko erabilgarria da [106], modu honetan hein handi batean neurketak egitearen ahalegina eta kostua murriztuz. Hala, antena dentsitate altuko guneak identifikatzea benetan lagungarria izan daiteke biztanleriaren esposizioa murrizteko neurriak hartzeko, hori beharrezkoa balitz. Era berean, ikerketa honen emaitzek interes handia pizten dute osasun publikoan, esposizioa zuzeneko neurketen bidez karakterizatzeko orduan lehentasunak ezarri ahal izatea ahalbidetuko baitu.

Herritarrek irrati-maiztasunekiko esposizioaren eta honek osasunean izan ditzakeen eraginen aurrean duten pertzepzioak indar handia hartu du azkenaldian gure gizartean. Europar Batasunean biztanleriaren % 20ak soilik baieztatzen du egon daitezkeen osasun arriskuen berri jaso izana eta % 25ak soilik uste du erakunde publikoek modu eraginkorrean egiten dietela aurre uhin elektromagnetikoek osasunean sor ditzaketen arazoei. Espainia da azken urteotan herritarren kezka gehien hazi den Europako estatua [93]. Lurralde ezberdinek, zein autonomi erkidegoek edota udal batzuek esposizioaren muga murriztaileagoak proposatu dituzte, eta honek, biztanleria, ezarritako mugak eta honek osasunean izan ditzakeen eraginak zalantzan jartzera eraman du. Guzti honek, biztanleriak administrazio publikoek IM-EEMekiko esposizioak sor ditzakeen arriskuen aurrean gauzatzen duten gestioaren inguruan mesfidantza sentitzea eragin du.

Ondorio gisa, gure ikerketa esparruan, bi inguru sentikor izan ezik gainerako guztiak telefonia mugikorraren antenengandik 100 m baino distantzia handiagora aurkitzen direla esan daiteke, distantzia hau CTE/23/2002 Aginduan esposizio mailak murrizteko ezarririkoa izanik. Dena den, kontuan hartuz distantzia ez dela esposizioan eragiten duen aldagai bakarra, beharrezkotzat jotzen da biztanleria orokorrak eta bereziki biztanleria sentikorrak jasaten duen benetako esposizioaren inguruko ikerketa sakon bat gauzatzea. Honek gaur egun osasun publikoan garrantzitsu bihurtu diren banakako, taldekako, zein erakunde mailako eskaerei erantzun egoki bat ematea ahalbidetuko du. Bestalde, esposizioak osasunean izan ditzakeen eraginen ikerketan sakontzea ahalbidetuko du, hala egungo segurtasun neurrien berrikuste egoki bat gauzatzea lagunduz.

ESKERRAK

Lehen egileak Eusko Jaurlaritzako Hezkuntza, Hizkuntza Politika eta Kultura saila eskertzen du jasotako doktorego-aurreko laguntzarengatik (PRE-2013_1_1145). INMA-Gipuzkoa kohorteko haurretan erradiazio ezionizazaileko eremu elektromagnetikoak karakterizatzeko proiektua Ekonomia eta lehiakortasun Ministerioak (FIS PI13/02187) eta ikerketa esparruko udaletxeek finantzatua izan da.

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2. HELBURUAK

Helburu orokorra

Eremu elektromagnetiko ez-ionizatzaileekiko (EEI-EEM) esposizioa ezaugarritzea INMA-Gipuzkoa kohorteko umeetan.

Helburu espezifikoak

- Oso maiztasun txikiko uhinen (ELF) eta irrati-maiztasuneko uhinen (IM) sortzaile diren iturrien identifikazioa eta geoerreferentziazioa
- Umeek euren egunerokoan ordu gehien ematen dituzten lekuen arteko alderatzea, esposizio mailen arabera, kontribuzio handiena duten lekuak identifikatuz
- Egunean zehar ume bakoitzak duen ELF eta IM mailak ezagutzea
- Bitarteko maiztasuneko uhinen esposizio mailak deskribatzea
- ELF eta bitarteko maiztasunen kasuan, eremu elektriko eta magnetikoen arteko erlazioa ikertzea
- IMen kasuan, iturri ezberdinen kontribuzioa kalkulatzea
- IMen kasuan, metodologia ezberdinen arteko konparazioa egitea, neurketa pertsonalak eta puntualak eginez
- Neurtutako ELFren eremu magnetikoaren esposizio mailek aldagai soziodemografikoekin eta ingurumen iturriekiko distantziekin lotura duten edo ez ikustea
- Kohorteko amen pertzepzio mailak ezagutzea, bai EEI-EEMen esposizioari bai osasunean izan ditzakeen arriskuei dagokienean
- Ezaugarri soziodemografiko eta pertzepzio mailen artean erlaziorik dagoen ikertzea eta EEMen esposizio mailei buruzko informazioa emateak pertzepzioan duen eragina ikertzea

3. METHODOLOGY

Characterization of exposure to non-ionizing electromagnetic fields in the Spanish INMA birth cohort: study protocol

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BMC Public Health 2016; 16:167[3]
DOI 10.1186/s12889-016-2825-3

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[3] Published in British English and modified to American English for the consistency of the thesis

ABSTRACT

Background

Analysis of the association between exposure to electromagnetic fields of non-ionizing radiation (EMF-NIR) and health in children and adolescents is hindered by the limited availability of data, mainly due to the difficulties on the exposure assessment. This study protocol describes the methodologies used for characterizing exposure of children to EMF-NIR in the INMA (INfancia y Medio Ambiente- Environment and Childhood) Project, a prospective cohort study.

Methods/Design

Indirect (proximity to emission sources, questionnaires on sources use and geospatial propagation models) and direct methods (spot and fixed longer-term measurements and personal measurements) were conducted in order to assess exposure levels of study participants aged between 7 and 18 years old. The methodology used varies depending on the frequency of the EMF-NIR and the environment (homes, schools and parks). Questionnaires assessed the use of sources contributing both to Extremely Low Frequency (ELF) and Radiofrequency (RF) exposure levels. Geospatial propagation models (NISMap) are implemented and validated for environmental outdoor sources of RFs using spot measurements. Spot and fixed longer-term ELF and RF measurements were done in the environments where children spend most of the time. Moreover, personal measurements were taken in order to assess individual exposure to RF. The exposure data are used to explore their relationships with proximity and/or use of EMF-NIR sources.

Discussion

Characterization of the EMF-NIR exposure by this combination of methods is intended to overcome problems encountered in other research. The assessment of exposure of INMA cohort children and adolescents living in different regions of Spain to the full frequency range of EMF-NIR extends the characterization of environmental exposures in this cohort. Together with other data obtained in the project, on socioeconomic and family characteristics and development of the children and adolescents, this will enable to evaluate the complex interaction between health outcomes in children and adolescents and the various environmental factors that surround them.

Keywords: Electromagnetic fields; radiofrequency; extremely low frequency; magnetic fields; child; adolescent; birth cohort; exposure assessment; environmental exposure

BACKGROUND

There is limited research on exposure to electromagnetic fields and its effects on children and adolescents. Both fetuses and children are especially vulnerable to persistent toxic chemicals in the environment, but evidence on health effects of electromagnetic fields of non-ionizing radiation (EMF-NIR) and whether the children are more vulnerable remains unclear [1,2].

Measuring exposure to EMF-NIR is a great challenge for researchers given, the ubiquity of the exposure, the diversity of sources, the spatial and temporal variability in emissions, and the different personal uses and behaviors in relation with the exposure sources, among other factors. There are different approaches for assessing the exposure which may be classified in indirect methods (distance to the emission sources, questionnaires and geospatial propagation models) and direct methods (spot and fixed longer-term measurements and personal measurements). The methodology also varies depending on the frequency of EMF-NIR. Usually EMF-NIR is divided in two big groups which are Extremely Low Frequency (ELF) fields and Radiofrequency (RF) fields which cover the frequency range between 0 Hz and 300 Hz and 10 MHz and 300 GHz respectively. Whilst there is a direct relation between magnetic and electric fields in RFs, there is not in ELFs due to the fact that the last are not measured in the far-field [3]. Therefore, separated measurement of magnetic (ELF-MF) and electric (ELF-EF) fields is needed when measuring ELFs. Intermediate frequencies (IFs) which cover the frequency range between 300 Hz and 10 MHz, do not tend to be analyzed on their own, there being a tendency to divide the NIR spectrum into ELFs and RFs, with IFs lying at the top and bottom of these two ranges respectively. Lastly, the differences in the study protocol of studies that use direct methods is also due to the environment where the assessment is done, i.e. outdoors (parks, playgrounds, etc.) or indoors (homes, schools, etc.).

Regarding indirect methods for assessing ELF radiation, initial studies estimated the exposure to this type of magnetic field (ELF-MF) using classification systems which take into account the proximity to high voltage power lines and the size and configuration of electrical wiring among other variables [4,5]. On the other hand, indirect methods for assessing exposure to RF fields have mainly considered the use of mobile or cordless phones [6–12], assessed using a questionnaire, or the distance between the home and the mobile phone base stations [13–15]. These indirect methodologies have been widely criticized since exposure estimated in these ways often does not correspond to levels obtained using exposimeters [16,17], being the use of the last ones the most accurate procedure for individual exposure classification.

Spatial propagation models are another indirect method for characterizing individual exposure. With regard to ELFs, Nassiri et al. [18] developed an interpolation method for estimating exposure to ELF-MFs, but the model has yet to be validated. We have not found any other geospatial model for assessing exposure to ELF-MFs and any model for assessing exposure to ELF-EFs. In contrast, various propagation prediction models have been developed for estimating environmental exposure to outdoor RF sources in recent years. Some of them only included RF exposure exclusively from mobile phone base stations [19–22]. Apart from assessing exposure from mobile phone base stations, the geospatial models developed by Anglesio et al. [23] and by Bürgi et al. (NISMap) [24] also assess exposure due to radio and television transmitters. While the model proposed by Anglesio et al. (2011) tends to overestimate the exposure, the NISMap has been validated and successfully used in epidemiological studies from Switzerland [24,25] and the Netherlands [26,27], showing a good correlation with spot measurements conducted indoors and outdoors. However, neither the aforementioned models consider RF exposure from individual use of electronic devices (mobile or cordless phones, tablets, computers, etc.) or indoor sources, such as Wireless Access Points for WiFi technology and cordless phone base stations. This information is usually collected using questionnaires.

The characterization of individual exposure to EMF-NIR by direct methods has been generally based on measurements in specific places at one point in time (spot), during a period of time (fixed longer-term) or by measurements using personal portable exposimeters over at least 24-hours to assess the exposure of individuals in their daily life (personal measurements) [28–30]. In contrast to indirect methods, direct methods are a better approach for assess the real EMF-NIR exposure and indirect methods should be contrasted or validated by direct methods.

The INMA (INfancia y Medio Ambiente- Environment and Childhood) Project (http://www.proyectoinma.org) is an ongoing prospective population-based birth cohort study concerned with the associations between pre- and post-natal environmental exposures and child growth and development [31]. This paper describes the methodologies for the characterization of the exposure to EMF-NIR in children from the INMA Project. This will enable us to evaluate, in a more comprehensive way, in later phases of follow-up, the complex interaction between EMF-NIR exposure and children's health and development as well as the environmental factors around them.

METHODS/DESIGN

The characterization of EMF-NIR exposure started in 2012. Part of the methodology described in this paper has been developed under two European projects, namely, the “Radiofrequency ElectroMagnetic fields exposure and BRAiN DevelopmenT study” (REMBRANDT Project) and “Generalised EMF research using novel methods. An integrated approach: from research to risk assessment and support to risk management” (GERoNiMO Project) (http://www.crealradiation.com).

Study population

The study population corresponds to five out of the seven Spanish regions (Menorca, Granada, Valencia, Sabadell and Gipuzkoa) involved in the INMA Project, including a total of 1900 children and adolescents aged between 7 and 18 years old [31].

Exposure assessment in the INMA-Cohort

Measurement equipment

The measurements of EMF-NIR were performed with several devices, all of them properly calibrated. The specifications of each measurement device are listed in Table 1. For measuring narrow- and broadband ELF fields and broadband RF fields strength, a NBM-550 Broadband Field Meter basic unit was used in one of the study regions, with an EHP-50D Electric Field and Magnetic Field and Flux Density Isotropic Probe Analyzer for fields of 5 Hz to 100 kHz and an EF 0691 Isotropic Probe for frequencies of 100 kHz to 6 GH, all from Narda Safety Test Solutions (Germany). In another study region, for broadband measurements at ELFs and RFs, a TS/001/UB Taoma Broadband Field Meter basic unit was used with TS/002/BLF and TS/003/ELF isotropic probes for analyzing the magnetic and electric fields respectively, in the 15 Hz-100 kHz frequency range and a TS/004/EHF isotropic electric field probe for the 100 kHz to 6 GHz frequency range, all from Tecnoservizi (Rome, Italy) [32,33]. For measuring narrowband RF fields in the 87.5 MHz–6 GHz range, ExpoM-RF 3 personal portable exposimeter (Fields at work; Zurich, Switzerland) was used in all the regions of the Project. In addition, the following were available: global positioning system devices (GPS), laser distance meters (Fluke 414D and Professional GLM 30, Bosch Brand), optical fiber cables to connect probes to the computer or the basic unit, and non-conducting tripods, as well as suitable software for data mining.

Table 1

Specification of the measurement devices

Measurement devices	EMF-NIR	Frequency range		Measurement range[a]	Manufacturer
		Broadband	Narrowband		
Basic unit NBM-550					Narda Safety Test Solutions
Probe EHP-50D	ELF-MF/EF	5 Hz-100 kHz[b]	Span of 100 Hz, 200 Hz, 500 Hz, 1 kHz, 2 kHz, 10 kHz, & 100 kHz[c]	0.3 nT-100 µT 5 mV/m-1 kV/m	
Probe EF-0691	RF	100 kHz-6 GHz	-	0.375 V/m-650 V/m	
Taoma basic unit TS/001/UB					Tecnoservizi
Probe TS/002/BLF	ELF-MF	15 Hz-100 kHz	Span of 5 kHz, 10 kHz & 100 kHz	100 nT-10 mT	
Probe TS/003/ELF	ELF-EF	15 Hz-100 kHz	Span of 5 kHz, 10 kHz & 100 kHz	10 V/m-100 kV/m	
Probe TS/004/EHF	RF	100 kHz-6 GHz	-	0.2 V/m-340 V/m	
Personal exposure meter (ExpoM-RF 3)	RF	-	16 bands (87.5MHz-6GHz)[d]	0.003/0.02[e] V m^{-1}-5 V m^{-1}	Fields at work

ELF: extremely low frequency; RF: radiofrequency; MF: magnetic field; EF: electric field; [a]The limit of quantification is the same as the lower limit of the measurement range; [b]It is possible to perform measurements with different spans or bandwidths; [c]The start frequency for each span corresponds to 1.2% of the span. The frequency bands are: 5-100 Hz; 5-200 Hz; 6-500 Hz; 12 Hz-1 kHz; 25 Hz-2 kHz; 120 Hz-10 kHz; 1.2-100 kHz. When in remote mode (disconnected from the control unit), 500 Hz is the minimum span that can be measured; [d]Frequency bands: 87.5 - 108 MHz; 470 - 790 MHz; 791 – 821 MHz; 832 – 862 MHz; 880 – 915 MHz; 925 – 960 MHz; 1710 – 1785 MHz; 1805 – 1880 MHz; 1880 – 1900 MHz; 1920 – 1980 MHz; 2110 – 2170 MHz; 2400- 2485 MHz; 2500 – 2570 MHz; 2620 – 2690 MHz; 3400 – 3600 MHz; 5150 – 5875 MHz; [e]Depending on the frequency band; Additional information regarding the equipment can be found in https://www.narda-sts.com/en/; http://www.westek.com.au/wp-content/uploads/2012/08/TAOMA-Brochure.pdf and http://www.fieldsatwork.ch/

Exposure characterization

Table 2 lists the types of methodologies carried out in each of the study regions of the INMA cohort involved in this research.

Table 2

Types of measurements and data collected in each INMA study area

	Sabadell	Gipuzkoa	Granada	Menorca	Valencia
Identification of sources					
ELF		✓	✓		
RF	✓	✓	✓	✓	✓
Questionnaires and time-activity diaries	✓	✓	✓	✓	✓
RF geospatial propagation model implemented and validated	✓	✓	✓	✓	✓
Short- and fixed longer-term EMF-NIR measurements					
Indoor					
Homes	✓	✓	✓	✓	✓
Schools		✓			
Outdoor					
Near homes			✓		
Public playgrounds/parks		✓			
School playgrounds		✓			
Personal RF exposure measurements	✓	✓	✓	✓	✓

ELF: extremely low frequency; RF: radiofrequency

1. Indirect methods for assessing EMF-NIR field exposure

1.1. Proximity to emission sources and questionnaires on sources use

Methodology

Information regarding characterization of sources that contribute to both ELF and RF fields in the environments of the study population (outdoor –playgrounds/parks– and indoor –homes and schools–), were requested to the pertinent companies (outdoor sources) and to the household members and school teachers (indoor sources). An exhaustive search of all sources that contribute to exposure to EMF-NIR was conducted.

Data requested for environmental outdoor ELF sources, consisted of the presence of high voltage power lines (≥132 kV) and electrical transformation substations (132 kV to 13.2 kV) and stations (13.2 kV to 250–300 V), located within a radius of 200 m from houses[4], schools and playgrounds. Moreover the railway network map is available for some of the study regions. In the case of outdoor environmental RF sources, mobile phone base stations and radio and television transmitters were identified. All of the appropriate parameters necessary for characterizing aforementioned RF sources were requested: location including coordinates (x, y, z), initial and final date of operation, height of the mast (measured from the surface on which it has been installed), type of transmitter, power, communication service, operating frequency, direction (azimuth), vertical orientation (electrical tilt) and number of carrier frequencies. Information regarding indoor environments was collected by questionnaire. Information concerning characteristics (location, height, facade and window frame materials, glazing, etc.), and size of the rooms in which measurements were made and the number and location of sources generating ELF fields (home appliances, music systems, televisions, computers, types of lighting and anti-theft systems) and RF fields (Wireless Access Points for WiFi technology and cordless phone base stations) was gathered. In addition, information on patterns of exposure (places visited by children on weekdays and at weekends, and habits regarding their use of the different abovementioned sources of EMF-NIR) was collected. If children had their own Android smartphone, the XMobiSense app (developed for Android) was installed on the device for a period of at least 4 weeks, in collaboration with the European Project "Characterization of the use of mobile phones in children, adolescents, and young adults" (MOBI-EXPO) [34]. This application measures the real use of mobile phones (number/duration of calls, SMS messages and data transfer), laterality, the use of hands-free controls, and the type of network connection used (2G/3G/4G/WiFi). This data are used to

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[4] Distance varied depending on the setting, explained in more detail in results

validate the information collected with the questionnaire. Lastly, parents' perception of the risks associated with exposure to ELFs and RFs was also assessed by questionnaire on a Likert-type scale ranging from 1 to 10.

Data analysis

Doing a comprehensive analysis and comparing the information gathered on outdoor emission sources and measurement results, the relationship between the proximity to these sources of radiation and exposure levels is analyzed. Relationship between indoor exposure levels and data collected through the questionnaire such as the presence and use of electronic and communication devices and characteristics of the buildings (age, materials, number of stories, etc.) is also studied.

Information on patterns of exposure (time spent in each environment and habits of using EMF-NIR emission appliances) is used along with data obtained with other indirect (geospatial propagation model) or direct methods (environmental and personal measurements) for exposure characterization of the study participants.

1.2. Implementation and validation of the geospatial propagation model for RFs, NISMap, for the INMA Spain study area

Methodology

The collected data on telecommunication transmitters (location, orientation, power, height, etc.), buildings (height, materials, type of windows, etc.) and the 3D environment geometry in each of the study regions are used to construct geospatial propagation models (NISMap) to estimate exposure to environmental outdoor RF radiation [24]. Spot measurements of RF fields carried out with ExpoM devices in homes and schools (explained in section 2.1) are used to validate the propagation model for each of the study areas.

Data analysis

Based on the levels of exposure from the NISMap propagation model, taking into account the time spent in each of the environment (homes, schools, and playgrounds/parks) and having georeferenced their locations, the exposure of 1900 INMA participants to RFs arising from mobile phone, TV and radio transmitters is characterized.

2. Direct methods for assessing EMF-NIR field exposure

2.1. Spot and fixed longer-term environmental measurements of EMF-NIR

Methodology

Spot and fixed longer-term measurements in ELF and RF ranges (5 Hz to 6 GHz) inside homes children's bedroom and living/dining room) and schools (classrooms) and outdoors (school playgrounds, public playgrounds/parks, and areas around the homes) were carried out (Table 3). The measurement methodology varies as a function of the type of field, frequency, and environment (indoors or outdoors), as well as the type of measurement equipment used.

Below, we describe some key aspects of some of these measurements that are not fully explained in Table 3.

Longer-term (17 to 24 h) measurements of ELF fields in homes (indicated in the column "Type of EMF-NIR" in the Table 3 by a superscript 1) consisted of initially placing the probe in the middle of the living/dining room, then moving it to the middle of the bedroom when the child went to bed and moving it back to the living/dining room in the morning, recording the times at which the device was moved [33].

Further, to identify the contribution of different RF sources (frequencies) to the total radiation exposure, spot (2 min) measurements of RF fields were carried in houses and classrooms (indicated in the column "Type of EMF-NIR" of the Table by a superscript 2), following the procedure described by Röösli et al. [28] and the European Committee for Electrotechnical Standardization [35]. Inside the houses, these measurements were made with doors and windows closed and when people were not present, to minimize potential interference, whereas at schools, they were carried out while the children were in the classrooms to avoid the inconvenience of taking them out of the room and to obtain exposure levels which correspond to school hours when the children are attending the class. The tracking procedure used for measuring RFs in public playgrounds/parks (indicated in the column "Type of EMF-NIR" of the Table by a superscript 3) involved moving across the whole area along a zigzag path at a constant speed to obtain a mean level of radiation and identify the points of maximum exposure. At the points where the highest levels were detected, we took an additional 20-min measurement to differentiate spot peaks from usual levels.

Table 3
Spot and fixed longer-term measurements of electromagnetic fields of non-ionizing radiation (EMF-NIR)

	N	**Type of EMF-NIR**	**Field**	**Frequency range**	**Duration (measurement interval)**	**Probe height**	**Measurement site**	**Measurement equipment**
INDOOR								
Homes								
Bedroom and living/dining room	123	ELF[1]	EF/MF	15 Hz – 100 KHz	17 h (240)	79 cm	Middle	Taoma
	300	RF[2]	EF/MF	16 bands (87.5 MHz-5.8 GHz)[e]	2 min (4 s)	1.7, 1.5 & 1.1 m[f]	Middle & corners[d]	ExpoM
Homes & schools		ELF	EF/MF	3 spans (100 Hz[b], 1 KHz, 100 KHz)[c]	Spot measurements	1.1 m	Middle & corners[d]	Narda
Bedroom, living/dining room and classroom	104[a] & 26[a]	ELF[1]	MF	6 - 500 Hz	24 h (30 s)	1.1 m	Middle	Narda
		RF	EF/MF	100 KHz – 6 GHz	2 min (1 s)	1.1 m	Middle	Narda
OUTDOOR								
Near homes	123	RF	EF/MF	100 KHz – 6 GHz	6 min (1 s)	1.45 m	2 m from the home	Taoma
Public playgrounds/parks	151	ELF	MF	6-500 Hz	20 min (30 s)	1.1 m	Middle	Narda
		ELF	EF/MF	3 spans (100 Hz, 1 KHz, 100 KHz)[c]	Spot measurements	1.1 m	Middle	Narda
		RF[3]	EF/MF	100 KHz – 6 GHz	Tracking	1.1 m	Whole area	Narda
		RF	EF/MF	100 KHz – 6 GHz	10 min (1 s)	1.1 m	Middle	Narda
		RF	EF/MF	16 bands (87.5 MHz - 5.8 GHz)[e]	6 min (4 s)	1.1 m	Middle	ExpoM
School playgrounds	26	ELF	MF	6 - 500 Hz	20 min (30 s)	1.1 m	Middle	Narda
		ELF	EF/MF	3 spans (100 Hz, 1 KHz, 100 KHz)[c]	Spot measurements	1.1 m	Middle	Narda
		RF	EF/MF	100 KHz – 6 GHz	20 min (1 s)	1.1 m	Middle	Narda
		RF	EF/MF	16 bands (87.5 MHz - 5.8 GHz)[e]	6 min (4 s)	1.1 m	Middle	ExpoM

RF: radiofrequency; ELF: extremely low frequency; EF: electric field; MF: magnetic field; [a]In Gipuzkoa 104 homes and 26 schools have been measured for the whole EMF-NIR range; [b]Only in the middle; [c]The start frequency for each span corresponds to 1.2% of the span. The frequency bands are: 5 -100 Hz; 12 Hz-1 kHz; 1.2-100 kHz; [d]At 1.4 m from the wall; [e]Frequency bands: 87.5 - 108 MHz; 470 - 790 MHz; 791 – 821 MHz; 832 – 862 MHz; 880 – 915 MHz; 925 –960 MHz; 1710 – 1785 MHz; 1805 – 1880 MHz; 1880 – 1900 MHz; 1920 – 1980 MHz; 2110 – 2170 MHz; 2400-2485 MHz; 2500 – 2570 MHz; 2620 – 2690 MHz; 3400 – 3600 MHz; 5150 – 5875 MHz; 1,2 and 3; methodology described in more detail in the text; [f]At 1.7, 1.1 and 1.5 m in the middle, and only at 1.5 m in the corners.

Data analysis

All direct measurements (spot and fixed longer-term) obtained in the houses, schools and playgrounds/parks are used to characterize the exposure to EMF-NIR in the different locations where the participants spend most of their time and to identify the locations that contribute most to their exposure. Measures of central tendency, such as arithmetic and geometric means, as well as the quadratic mean (RMS), standard deviation, median, and range of exposure to EMF-NIR (5 Hz-6 GHz) in each environment are calculated. In indoors environments, where spot measurements are done both in the center and corners the mean for each room was calculated taking into account all the measurements. Moreover, for each of the environments analyzed, spectral analysis of the exposure levels are carried out, from the data obtained with the devices measuring narrowband radiation (NARDA EHP-50D and ExpoM RF 3). In this way, the value of each of the spectral components, that is, the different frequency bands that contribute to the total level is ascertained, and the main sources of ELF and RF emissions are identified. In addition, longer-term measurements are used to assess spatial and temporal variability in levels of exposure.

Further, with the exposure levels calculated for each environment, together with the data on time-activity patterns from the questionnaires, levels of individual exposure are estimated, considering the time children spend in each location. In this way, individual level of exposure to EMF-NIR in the 5 Hz to 6 GHz frequency range from environmental (internal and external) sources is assigned to a subsample of 200 children (see Table 3). This methodology does not consider exposure due to the personal use of information and communication technology devices or other electrical appliances.

2.2. Personal measurements of children's and adolescents' individual RF exposure

Methodology

Individual measurement to EMFs across 16 frequency bands (between 87.5 MHz and 5.87 GHz) were obtained in 300 children from all study regions, using ExpoM-RF 3 personal RF exposimeters with a measurement interval of 4 s. The procedure consisted of children wearing the exposimeter up to three consecutive days (72 h), the device being placed in a padded belt bag, with no metal items. They were advised to wear the bag around the waist when possible during the day. At night, children placed the exposimeter on a flat non-metallic surface, as close as possible to their bed. The exposimeters used had a GPS which provides data on the location of the participant at all times. Participants or, in the case of children their parents, also completed an activity diary recording their schedule during measurements days and a questionnaire concerning the measurement period asking them about: their activities and places they had been; the place they had kept the belt bag with the exposimeter most of the time (rucksack, waist, etc.), and whether, and if so for how long, they had used RF sources (mobile phone, and if so, where they kept it, cordless phone, computers, tablets and videogames with Internet via WiFi, 3G/4G or cable). In a subsample of 30 children we performed a repeatability study one year later following the same protocol.

Data analysis

Data on personal measurements will be combined with the information recorded in the activity diary in order to provide additional relevant information related to RF exposure levels of 16 different frequency bands in different environments and its spatial and temporal variability, as well as the sources of emission and activities of the children that contribute most to their RF exposure in outdoor and indoor environments. Moreover, the repeatability study will enable to investigate the reproducibility and temporal variation of RF exposure in children one year later[5].

DISCUSSION

The methodology proposed in this paper will enable the characterization of exposure to EMF-NIR in children and adolescents, including i) ELFs and RFs by means of direct methods in around 200 participants (spot and fixed-long term measurements), ii) total RF exposure, including environmental and personal exposure, in 300 participants by means of direct methods (personal measurements) and iii) outdoor environmental RF exposure in 1900 participants by means of indirect methods (NISMap modeling). This represents a sound base for future research into potential effects of EMF-NIR exposure on health, such as neuropsychological development and contributes to the current knowledge on the characterization of EMF-NIR exposure [36].

Multiple factors are involved in the interactions between children environment and health. The use of EMF-NIR sources is gradually increasing among children and adolescents, and hence, it is important to consider this type of exposure in cohort studies investigating the effects of exposure to environmental hazards. The INMA Project has previously collected data on prenatal and postnatal exposure to several chemical pollutants and has assessed the association between this exposure and the growth and development of children at different

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[5] This analysis will be part of another doctoral thesis of an INMA researcher

childhood stages. The evaluation of exposure to different sources of EMF-NIR extends the characterization of environmental exposures in this cohort.

Many epidemiological studies have characterized EMF-NIR exposure partly, and several have assessed the effects of some sources of EMF-NIR on health. To investigate the relationship between EMF-NIR exposure and potential effects, it is essential to carry out a proper characterization of this exposure. The most common criticisms of studies describing effects associated with EMF-NIR are the methodology used for characterize exposure and failing to take into account most of the sources of emission [16,17]. In particular, exposure to ELFs has generally been estimated by indirect methods such as those described by Wertheimer and Leeper [4]. However, studies are starting to emerge in which ELF exposure is estimated by spot and longer-term direct measurements, and taking into account all the potential sources of emission [33], while others use personal measurements [37]. With regards to RFs, the majority of studies published on the effects of RF exposure on health consider the use of mobile and cordless phones (900 MHz to 2600 MHz), with data mostly from questionnaires [6–8,38], not taking into account environmental sources of RF EMFs (mobile phone base stations, radio and TV transmitters, WiFi and cordless phone base stations), to which children are exposed on a daily basis, at school and/or at home. These studies analyze the effects of the exposure to RF radiation from devices operated close to the body, generally to the head, from time to time and for short periods. However, radiation from RF environmental sources tends to be more homogeneous and weaker than that from the aforementioned sources, but exposure involves the entire body and continues for longer periods of time.

In our study, indirect and direct methods have been used for the characterization of the exposure to EMF-NIR. Regarding indirect methods, information was collected on the proximity of different environments (houses, schools and parks) to RF transmitters and electricity transmission and distribution lines and on the use of ELF and RF emission sources by questionnaires. However, to avoid the limitations of the use of this type of indirect method, the gathered information is not used on its own for the exposure assessment but to complete and improve the characterization done using other methods. Furthermore, using the XMobiSense app, we have overcome the problems related to assessing mobile phone use with questionnaires, which tend to underestimate the number of calls made/received and overestimate the length of the calls [34,39]. Although we will be able to obtain a good estimate of the real use of mobile phones, this will only be possible in the case of the oldest children with their own smartphone. Moreover, we will not count with the information on the output power of the mobile phone, which is essential for the exposure characterization. In order to solve it, the participants provide information regarding the specific brand and model of the mobile phone they use most.

Within indirect methods, geospatial propagation models may be a good alternative to direct methods estimate environmental exposure of the population to RFs arising from mobile and radio/TV base stations, since they significantly reduce the need for materials and overall costs. However, they require high quality data to be available on the technical specifications of the emitters, as well as the geospatial characteristics of buildings in the area. Further, this methodology does not allow to estimate the level of exposure to non-environmental sources such as mobile phones and other wireless communications systems, including WiFi or cordless phone base stations. On the other hand, provided that technical information from the emitters and land registry is available, the NISMap model is a useful tool since it makes it possible to estimate retrospective exposures.

To our knowledge, models have not yet been developed and validated to predict ELF exposure. For this reason, characterization of exposure to radiation in this frequency range relies on direct methods, as well as the collection of information on environmental sources of exposure such as high- and medium-voltage power lines and others, including home appliances.

For reliable characterization of exposure using direct methods, the selection of measurement devices is of great importance, especially with respect to the limit of quantification. We have used Narda and Taoma devices to measure broadband RFs, which have measurement ranges (0.375 to 650 V/m and 0.2 to 340 V/m respectively) that enable us to check whether exposure levels are within legal limits [40], but many of the fields measured with these systems were below the limit of quantification (0.375 and 0.2 V/m) [32]. This limitation has been partially overcome by use of the personal narrowband exposimeter (ExpoM-RF 3) which has a lower limit of quantification (0.003 to 0.02 V/m, depending on the frequency band). This allows us to determine, on the one hand, children’s exposure levels with a greater accuracy, and on the other, the types of sources that contribute most to these levels. Another important point to consider is the height at which measurements are taken to enable comparisons between the results of different studies. In relation to this, the Institute of Electrical and Electronics Engineers recommends measuring RF fields at a height of up to 2 m [41] and ELF fields at 1 m [42] above the floor. We measured RFs at 1.1, 1.45, 1.5 and 1.7 m and ELFs at 0.79 and 1.1 m above the floor, considering the different ages and heights of the participants involved (7 to 18 years old).

Spot and fixed longer-term measurements make possible to carry out the estimation of exposure to the full range of EMF-NIR, including ELF and RF (5 Hz to 6 GHz). However, the frequency ranges at which emitters are operated and spatial and temporal variability in emissions govern the levels of indoor and outdoor exposure, and in turn, individual exposure fluctuates depending on these factors. Hence, according to some authors, the estimates obtained from spot and fixed longer-term measurements may not be fully representative of personal exposure levels [16]. Another disadvantage of this methodology is the great effort required in terms of time and resources, and for this reason, we are only making estimates of both ELF and RF exposure from direct measurements in a subset of around 200 children from the cohort. Resource limitations mean that we will only be able to carry out a comprehensive characterization of EMF-NIR exposure for children in whose homes measurements of the whole frequency range have been made.

Estimating individual levels of RF exposure using a personal exposimeter (ExpoM) should provide us with more realistic data. However, this methodology has some limitations in that it may alter the real exposure as reported by Frei et al. [43], due to shielding effects or potential variations in the normal behavior of children when using the device.

Besides our study, other epidemiological studies, such as the HERMES [30] and the ABCD [27,44] cohort studies in Switzerland and the Netherlands respectively, the cross-sectional MoRPhEUs study in Australia [11] and the multicenter case control CEFALO study in Scandinavian countries and Switzerland [8] have characterized RF exposure. With the exception of ABCD cohort, the rest were created with the aim of assessing the exposure and effects of RF fields. As well as the INMA cohort study, other European cohorts that are involved in the GERoNiMO Project (ABCD, HERMES and the Danish DNBC child cohort [45]) will have information on RF exposure along with data on other covariates. However, to date, we have not found any cohort studies that explore exposure to the whole range of EMF-NIR frequencies and that also provide information on exposure to a large number of environmental pollutants and covariates such as that analyzed in the INMA cohort study.

To our knowledge, there is just one previous study comprehensively characterizing RF exposure that has also assessed its effects on neuropsychological development [46]. Research in this field is limited to challenge studies using volunteers subjected to acute exposure to certain RFs [47–49]. Regarding exposure to the magnetic component of ELF fields, most studies have focused on a potential carcinogenic effect [50], although some have also explored adverse effects on cognitive functions in children [51,52].

In conclusion, our work will contribute to understanding the main sources of EMF-NIR exposure in children and adolescents at different ages (from 7 to 18 years old) and their contribution to exposure in daily life, since these may differ from patterns in adults [29,53,54] or in adolescents from other countries [30]. Such information is essential to assess the relevance of each source of exposure to child development and together with other project data, on socioeconomic and family characteristics, and children's health, will allow us to assess more comprehensively, in later stages of follow-up, the complex interaction between the children's health and development and various environmental factors that surround them.

Finally, given advances and changes in technology and constantly changing patterns in its use, exposure to EMF-NIR should be studied continuously at different stages during childhood, to improve our understanding of their real exposure and its potential effects on their health, as well as analyze the relevance of cumulative exposure over time.

ACKNOWLEDGMENTS

We would like to thank all INMA families for their active collaboration, this being essential for achieving the objectives of the INMA Project. MGa would like to thank the Department of Education, Language Policy and Culture of the Government of the Basque Country for a predoctoral research training grant. The characterization of the exposure to non-ionizing electromagnetic radiation in children of the INMA Gipuzkoa cohort has been funded by the Spanish Ministry of Economy and Competitiveness (FIS) and by the councils of the study areas. This study was funded by grants from the Spanish Instituto de Salud Carlos III Health Institute (PI13/02187 incl. FEDER funds, CP13/00054 incl. FEDER funds, MS13/00054), the councils of the study region of Gipuzkoa and the EU Commission (603794).

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4. RESULTS

Exposure to extremely low and intermediate-frequency magnetic and electric fields among children from the INMA-Gipuzkoa cohort

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Environmental Research 2017; 157:190–197

DOI: 10.1016/j.envres.2017.05.027

ABSTRACT

Detailed assessment of exposure to extremely low frequency (ELF) and intermediate frequency (IF) fields is essential in order to conduct informative epidemiological studies of the health effects from exposure to these fields. There is limited information available regarding ELF electric fields and on both magnetic and electric field exposures of children in the IF range. The aim of this study was to characterize ELF and IF exposure of children in the Spanish INMA cohort. A combination of spot and fixed measurements was carried out in 104 homes, 26 schools and their playgrounds and 105 parks. Low levels of ELF magnetic fields (ELF-MF) were observed (with the highest 24-hour time-weighted average (TWA) exposure being 0.15 µT in one home). The interquartile range (IQR) of ELF electric fields (ELF-EF) ranged from 1 to 15 V/m indoors and from 0.3 to 1.1 V/m outdoors and a maximum value observed was 55.5 V/m in one school playground. IQR ranges for IF magnetic and electric fields were between 0.02 and 0.23 µT and 0.2 and 0.5 V/m respectively and maximum values were 0.03 µT and 1.51 V/m in homes. Correlations between magnetic and electric fields were weak for ELF (Spearman 0.04 to 0.36 in different settings) and moderate for IF (between 0.28 and 0.75). Children of INMA-Gipuzkoa cohort were exposed to very low levels of ELF-MF in all settings and to similar levels of ELF-EF compared to the range of previously reported levels, although somewhat higher exposures occurred at home. Children enrolled to our study were similarly exposed to IF in all settings.

Keywords: Exposure assessment; electromagnetic fields; extremely low frequency; intermediate frequency; children

Abbreviations

ELF: extremely low frequency; ELF-MF: extremely low frequency magnetic field; ELF-EF: extremely low frequency electric field; IF: intermediate frequency; IF-MF: intermediate frequency magnetic field; IF-EF: intermediate frequency electric field; EMF: electromagnetic field; INMA: Environment and childhood (from INfancia y Medio Ambiente) cohort; THD: total harmonic distortion; IARC: International Agency for Research on Cancer; RF: radiofrequency; WHO: World Health Organization; SCENIHR: Scientific Committee on Emerging and Newly Identified Health Risks; TWA: time-weighted average

Highlights

- Extremely low and intermediate frequency electromagnetic field levels were assessed
- We measured in children’s homes, schools, playgrounds and parks
- 95th percentiles of magnetic field levels were low in all settings (≤0.07 µT)
- Electric field levels (P95) ranged from 1 to 30 V/m between settings
- We provide the first data on intermediate frequencies in children’s settings

INTRODUCTION

Exposure to extremely low frequency (ELF) electromagnetic fields (EMFs) is ubiquitous in the general population. Since in 1979 Wertheimer and Leeper [1] found a doubling of the risk of leukemia in children living near high current configurations, many researchers have made efforts to investigate this association [2,3]. Due to the observed elevated risk of leukemia in children exposed to levels above 0.4 µT of ELF magnetic fields (ELF-MF), these EMFs were classified as possibly carcinogenic to humans by the International Agency for Research on Cancer (IARC) in 2002. Nevertheless, the association between exposure and other health effects remain unclear [4,5].

Great efforts have been made to characterize magnetic fields, but there is less data available regarding exposure to ELF electric fields (ELF-EF). Regarding interaction with the human body, electric fields also charge the body surface. If they are strong enough they can induce electric currents inside the body and stimulate nerve and muscle cells [4], but this occurs only in the case of very high exposures above 5000 V/m [6]. Electric fields are attenuated by most common building materials and objects whereas magnetic fields are able to penetrate such materials [7,8]. Hence, electric fields from outdoor sources are weaker in indoor settings and exposure to ELF-EF inside buildings is mainly due to indoor sources such as electrical wiring and home appliances. Notably, electric fields are more complicated to measure and characterize, mainly due to their higher spatial variability and the fact that they are perturbed easily by any conducting material, which is possibly one of the reasons behind the scarcity of studies in this field.

The World Health Organization (WHO) categorizes electromagnetic fields of non-ionizing radiation (EMF-NIR) into three major groups apart from static fields (i.e., 0 Hz): ELF fields from >0 to 300 Hz, intermediate frequency (IF) fields from 300 Hz to 10 MHz and radiofrequency (RF) fields from 10 MHz to 300 GHz [9]. In the scientific literature, ELF is often used to refer to the frequencies ranging from >0 Hz to 100 kHz, that is, partially overlapping with the aforementioned IF range. IF-emitting sources are not very common, although the number of electric devices using these frequencies has been on the rise over recent years and include, for example, induction hobs, liquid-crystal displays (LCDs), fluorescent lightning and some types of microwave ovens [10]. Some studies have described exposure levels from these sources and observed that, in close proximity, IF magnetic fields (IF-MF) may exceed reference levels [11,12]. Such high exposure levels are likely not representative of the average population or children´s exposure levels. To the best of our knowledge, however, no studies have assessed IF exposure levels in general population settings under conditions of daily life [4]. Comprehensive exposure assessments are essential both for acquiring knowledge on current levels of exposures and for conducting future epidemiological studies. For this reason, and given the lack of data, characterization of children's exposure to ELF-EF and to IF-MF and IF electric fields (IF-EF) was identified as a priority by the WHO [13–15] and by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) [4].

This study was conducted within the INMA-Gipuzkoa (*Infancia y Medio Ambiente*– Environment and childhood) birth cohort (www.proyectoinma.com) [16]. The aim of the study presented here was to characterize the exposure to ELF-MF, ELF-EF, IF-MF and IF-EF in the settings where the children tend to spend most of their time, i.e., in homes, schools and public open spaces, namely, parks and urban squares (hereon "parks").

METHODS

Study population

INMA-Gipuzkoa is part of the Spanish INMA birth cohort and is located in the Basque Country. The INMA cohorts have been described in detail elsewhere [16].

In brief, the recruitment of mother-child pairs took place during the first antenatal visit (10-13 weeks of gestation) to the physician in the public referral hospital (Zumarraga hospital) between April 2006 and January 2008.

In total, 638 out of 993 mother-child pairs invited to participate met the inclusion criteria and were enrolled in the study. Over the period 2014 to 2016, when the children reached 8 years of age, cohort members were contacted; at that time, 395 children (61.9%) participated in the study.

Study procedure

We performed ELF-MF, ELF-EF, IF-MF and IF-EF measurements in places where children tend to spend most of their time, specifically, in homes, schools and parks. Due to time constraints, home measurements were performed in the living room and child's bedroom of a subsample of 104 households. Participants for these measurements were selected primarily based on their availability, as nearly all cohort members contacted agreed to have measurements performed in their homes (386 of 397 contacted, 97.2%). Families who gave consent were randomly contacted when the children were 8 years±3 months to determine the date and time for the measurements. If the families were available (and not e.g. on holidays) and it was possible to arrange an appointment with the study assistant to make the measurements in their homes, they were carried out. All primary schools in the study area (n=26) were included in our measurement survey, given that our children are distributed within those schools. In each school, in order to have an overall idea of the levels on the areas of the schools where our participants use to be, measurements were taken in two classrooms of INMA children as well as the main school playground. Classrooms with greater number of INMA students were selected in each grade (second and third year of primary school). All cohort members filled in a questionnaire that inquired, among other items, about the parks and other public spaces where the children spent most time. For that purpose, we provided them with a list of parks that they had mentioned during previous follow-ups and they were allowed to add other relevant parks to the list. From this full list of parks (125), 105 (84%), including those most frequently named by families, were selected for the measurements, since we assumed that these parks represented those where children were most likely to spend most of their time.

Measurement devices

We used two EHP-50D electric field and magnetic flux density isotropic probe analyzers for frequencies between 5 Hz to 100 kHz together with a NBM-550 Broadband Field Meter Basic Unit, all from Narda Safety Test Solutions (Germany). The three axes are measured simultaneously, resulting in true root-mean-square measurements, but magnetic flux density (further referred to as magnetic fields) and electric fields are measured in sequence. The device also offers the possibility of narrowband spectrum analysis, to allow the user to estimate the contribution from a selected frequency band to the total broadband measurement. The EHP-50D allows relatively long-term measurements, up to 24 hours, in stand-alone mode and it also allows spot measurements when connected to the Basic Unit. The highest resolution of the probes was selected, i.e., 1 nT and 1 mV/m when measuring in stand-alone mode and 0.1 nT and 1 mV/m with the Basic Unit for the magnetic and electric fields respectively. The measurement range was from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields for all measurements. Total expanded uncertainty of the probes has been described to be up to 8% for magnetic field and up to 15% for electric field [10]. The devices were calibrated by the manufacturer prior to the measurement survey. Post-survey calibration showed very little deviation in accuracy; up to 3% for the magnetic field and up to 7% for the electric field.

Measurement procedure

Measurements were made following the methodology detailed in a previous publication [17]. In brief, short-term spot magnetic and electric field measurements (32 consecutive readings) were carried out in homes, schools and parks. Spot measurements were made at the center and in the four corners of rooms (homes and school classrooms), at 1.10 m above the floor (considering the age and heights of the participants) and at 1.40 m (diagonally) from the corners, in order to capture variability of exposure across the room. Similar procedures have been previously suggested for ELF-MF fields [18], as well as for RF-EMF fields [19]. Outdoor measurements were only taken in the center of the corresponding space (geographical center or center of the children´s play area in the case of parks with playground equipment). We selected measurement bandwidths (spans) in order to cover the total measurement range of the device. The minimum starting frequency of each span is 5 Hz or 1.2% of the selected span, specifically, 100 Hz, 1 kHz and 100 kHz. In line with this, the 100 Hz setting measures the band from 5 to 100 Hz, the 1 kHz setting from 12 Hz to 1 kHz and the 100 kHz setting from 1.2 kHz to 100 kHz. Note that the last of these bandwidths falls into the IF range.

In addition, we performed longer-term measurements of ELF-MF, which consisted of 24-hour measurements in homes and classrooms but just 20-minute measurements in school playgrounds and parks, since the devices needed to be supervised outdoors and longer periods of supervision were not feasible with the available resources. In schools, the probe was placed in the center of each classroom, while in homes, probes were placed in the center of the living room during the day and in the center of the child's bedroom when the child went to bed. Given variability of bedtimes across children, this timing was not identical across our study participants (Median/IQR of hours that the device was placed in the living room was 13.4/13-14 hours). In playgrounds and parks, the probe was placed in the center (as for spot measurements, in the geographical center or in the center of play area). The frequency spans when measuring in 24-hour and 20-minute modes differ from those when measuring spots using the hand-held Basic Unit. For 24-hour and 20-minute measurements, we selected the lowest possible span, which is 500 Hz (corresponding to the frequency band from 6 Hz to 500 Hz). Measurements were taken at 30-second intervals (lowest selectable measurement interval for stand-alone mode).

All measurements were conducted from Monday to Friday, although 24-hour measurements in homes could include some hours of Saturday. Time of spot measurements at homes was variable, depending on the availability of the families, with preference to afternoon hours, usually when children would be at home. Given that our aim was to assess the levels of exposure to which children are usually exposed to, all measurements were taken under the conditions in which they normally are. Thus, in indoor settings, i.e. in homes and classrooms, the appliances were set as they would be when the children are there. According to the manufacturer, operating relative humidity was up to 95% and operating temperature of the probes ranged from -20 to +55 °C. All of our measurements were conducted under these conditions. Characteristics of the measurements that were carried out are summarized in Supplementary Table 1.

Data collection

Previous studies have found that type of area, type of building, number of floors and building year are relevant factors in magnetic field exposure [20–22]. Therefore, we collected data on these factors together with others that we considered that might affect exposure levels. A questionnaire completed by the parents was used to gather data on: characteristics of the building where they lived (floor number of the property, total number of floors in the building, type of dwelling [detached/semi-detached house, building with 2-8 apartments or building with more than 8 apartments], period when the building was completed [up to 1990 or more recently] and type of area [rural or urban]); number of adults and children living in the household; parks and other public spaces most frequently visited by the children; and mean time spent in each setting. In schools, teachers were asked whether televisions, computers, projectors and/or electronic whiteboards were regularly used in classrooms. We also requested information regarding proximity of our measurement sites to outdoor sources of EMF, such as power lines and transformers, from the energy distribution and generation companies operating in the area. Details of the information requested are provided in Supplementary Table 2.

Data handling and statistical analysis

We evaluated if our participants differed from the whole study collective in terms of relevant characteristics but no statistically significant differences were observed (Supplementary Table 3).

We calculated descriptive statistics for both spot magnetic and electric field and time-weighted average (TWA) (24-hour and 20-minute) ELF-MF measurements. Variations in ELF-MF over the day were explored in the settings with 24-hour data (homes and school classrooms). We also calculated Spearman's correlation coefficients of spot ELF-MF with ELF-EF and IF-MF with IF-EF levels for measurements made in the same location (and not considering a mean value for the room). For approximately one third of the homes (n=37, 36%), we only performed spot measurements of magnetic fields in the center of the rooms, rather than in the center and all four corners. Data from homes with complete information and homes with partial information were treated separately.

In addition, we checked whether any frequency ranges made a dominant contribution to overall IF-MF exposure. Mann-Whitney U and Kruskal-Wallis tests were performed to check differences between settings in exposure to ELF-MF (comparing outdoor and indoor settings) and ELF-EF (comparing homes, schools and parks) respectively.

Total harmonic distortion (THD) for ELF-MF was calculated for the main contributing harmonics (up to the sixth harmonic), using the 1 kHz frequency measurement range that included these harmonics.

We also explored potential explanatory variables for observed TWA ELF-MF exposures (over 24 hours indoors and 20 minutes outdoors). For homes, we calculated Spearman´s correlation coefficients between exposure and the following: the number of adults and children per household; floor of the property; and total number of floors in the building; and we performed non-parametric Mann-Whitney U test for age of the building (completed up to 1990 or more recently) and Kruskal-Wallis test for type of dwelling (detached or semi-detached house, multiple storey building with 2-8 apartments or multiple storey building with more than 8 apartments). For school classrooms, Mann-Whitney U tests were performed to investigate potential associations between magnetic field exposures and use of televisions, computers, projectors and/or electronic whiteboards. In all settings (homes, schools and parks), presence or absence of outdoor EMF sources like transformers, substations and power lines within certain distance (specified in Supplementary Table 2) was explored with non-parametric Mann-Whitney U tests (comparing groups that did or did not have each source within a previously established distance) and Kruskal-Wallis tests (comparing groups classified by the number of sources of each type). P values below 0.05 were considered as statistically significant.

Finally, we calculated and compared estimated TWA based on home exposure only and based on all settings (homes, schools and parks) for magnetic and electric fields respectively. The Cohen´s kappa coefficient was used to assess agreement between both approaches.

Data were analyzed with Stata (version 12; StataCorp, College Station, TX, USA).

RESULTS

Between November 2014 and February 2016, we performed measurements in 104 homes, 26 schools and 105 parks. Descriptive statistics of the TWA ELF-MF exposure levels over 24 hours for indoor settings and 20 minutes for outdoor settings are provided in Table 1 and in

Supplementary Figure 1. The highest ELF-MF exposure detected among all mean exposure levels captured with 24-hour measurements values was 0.145 µT in one home.
Hourly patterns of ELF-MF exposures showed slightly higher exposure in the evening in homes and during the day in school classrooms (Supplementary Figure 1), although differences were not very pronounced (Table 1). The highest mean ELF-MF hourly exposure was 0.19 µT in one home.

Data from spot measurements of ELF and IF magnetic and electric fields are summarized in Table 2. For magnetic field, mean levels of ELF and IF exposure ranged from 0.013 to 0.028 µT across the different settings and frequency ranges. Levels of ELF-MF exposure were slightly lower outdoors than indoors (Mann–Whitney U test p values were <0.01 for 100 Hz and 1 kHz spans). Average levels of ELF-EF exposure varied between 1.495 and 10.106 V/m across the different settings. Lower levels were obtained for IF-EF, with average exposures from 0.376 to 0.453 V/m. The highest and lowest ELF-EF levels were found in homes and parks respectively (Kruskal-Wallis test p values were <0.01 for 100 Hz and 1 kHz spans).

The correlation between magnetic and electric ELF fields based on spot measurements (average of 32 consecutive samples) was low (correlation coefficients ranging from 0.044 to 0.357 across the different settings and frequency ranges) but higher correlations were observed for IF fields (from 0.285 to 0.752) (Table 3).

No frequencies made a dominant contribution to exposure in any of the separate spans in the IF frequency range (data not shown).
Median THD (calculated up to the sixth harmonic) for all the settings combined was 0.45 and 0.11 for magnetic and electric fields respectively (Supplementary Table 4).

Table 1

Descriptive statistics of the ELF magnetic field (longer-term measurements)[1,2]

	Homes (24 hours) (µT)	School classrooms (24 hours) (µT)	School playground (20 min) (µT)	Parks (20 min) (µT)
N	103[c]	52	26	105
Mean (SD)	0.019 (0.015)	0.017 (0.015)	0.015 (0.008)	0.018 (0.019)
GM (GSD)	0.016 (1.615)	0.015 (1.694)	0.013 (1.540)	0.014 (1.807)
Median (IQR)	0.014 (0.012-0.019)	0.012 (0.010-0.017)	0.011 (0.010-0.013)	0.012 (0.010-0.016)
P95	0.043	0.050	0.035	0.064
Minimum- Maximum	0.010-0.145	0.009-0.100	0.009-0.035	0.009-0.117
Mean day			-	-
08:00-16:59	0.019 (0.020)			
09:00-16:59[a]		0.018 (0.016)		
Mean evening			-	-
17:00-22:59[b]	0.020 (0.018)	0.017 (0.015)		
Mean night (23:00-07:59)	0.017 (0.014)	0.017 (0.017)	-	-

ELF: extremely low frequency; SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation; IQR: interquartile range; P95: 95th percentile; we provide magnetic flux density values; [1]Measured frequency range was between 6 and 500 Hz and the device was used in stand-alone mode. [2]Calculations have been made using the mean values obtained for the whole measurement time in each setting; [a]These are approximately equivalent to the usual school hours in primary schools; [b]For the school classrooms, the time period from 8 to 9 am is also included in this row, in order that the mean provides an idea of the exposure levels when there are no formal classes but people may also be working in the building; [c]One reading from a home was lost during recording process; Measurement range of the probe: from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields respectively.

Table 2

Spot measurements of magnetic and electric fields

	N			Mean (SD)			GM (GSD)			Median (IQR)			P95		
	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz
Magnetic field (μT)															
Homes															
Living room	99[a]	104	104	0.018 (0.018)	0.027 (0.202)	0.023 (0.000)	0.015 (1.731)	0.024 (1.494)	0.023 (1.018)	0.012 (0.010-0.017)	0.021 (0.020-0.025)	0.023 (0.022-0.023)	0.053	0.050	0.023
Only center	99	104	104	0.018 (0.018)	0.025 (0.019)	0.023 (0.001)	0.015 (1.731)	0.022 (1.484)	0.023 (1.039)	0.012 (0.010-0.017)	0.020 (0.018-0.023)	0.023 (0.022-0.023)	0.053	0.050	0.023
Corners		67	67		0.027 (0.019)	0.023 (0.000)		0.024 (1.464)	0.023 (1.016)		0.022 (0.019-0.025)	0.023 (0.022-0.023)		0.054	0.023
Child´s bedroom	99[a]	104	104	0.017 (0.017)	0.025 (0.024)	0.023 (0.000)	0.014 (1.659)	0.022 (1.453)	0.023 (1.014)	0.011 (0.010-0.017)	0.020 (0.019-0.0229)	0.023 (0.022-0.023)	0.042	0.044	0.023
Only center	99	104	104	0.017 (0.017)	0.023 (0.015)	0.023 (0.000)	0.014 (1.659)	0.022 (1.372)	0.023 (1.017)	0.011 (0.010-0.017)	0.020 (0.018-0.023)	0.023 (0.022-0.023)	0.042	0.033	0.023
Corners		67	67		0.027 (0.032)	0.023 (0.000)		0.023 (1.542)	0.023 (1.013)		0.020 (0.019 -0.023)	0.023 (0.022-0.023)		0.058	0.023
School															
Rooms[b]	52	52	52	0.018 (0.018)	0.028 (0.020)	0.023 (0.000)	0.014 (1.707)	0.025 (1.556)	0.023 (1.012)	0.012 (0.010-0.017)	0.021 (0.019-0.026)	0.023 (0.023-0.023)	0.047	0.069	0.023
Playgrounds	26	26	26	0.013 (0.008)	0.021 (0.007)	0.023 (0.000)	0.012 (1.519)	0.021 (1.278)	0.023 (1.011)	0.011 (0.009-0.011)	0.019 (0.018-0.020)	0.023 (0.022-0.023)	0.032	0.041	0.023
Parks	104	67	103	0.017 (0.018)	0.023 (0.017)	0.022 (0.001)	0.013 (1.790)	0.020 (1.502)	0.022 (1.024)	0.010 (0.009-0.014)	0.018 (0.016-0.020)	0.022 (0.022-0.022)	0.051	0.057	0.023

Table 2 (continued)

	N			Mean (SD)			GM (GSD)			Median (IQR)			P95		
	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz	5-100 Hz	12 Hz-1 kHz	1.2-100 kHz
Electric fields (V/m)[c]															
Homes															
Living room	65	104	104	6.901 (8.955)	8.891 (6.312)	0.376 (0.151)	3.758 (2.971)	6.762 (2.215)	0.353 (1.411)	3.196 (1.630-7.223)	7.646 (4.012-11.957)	0.360 (0.262-0.429)	30.256	22.125	0.585
Child´s bedroom	65	104	104	8.643 (8.594)	10.106 (7.887)	0.385 (0.164)	4.881 (3.249)	7.179 (2.457)	0.361 (1.422)	5.942 (2.103-13.035)	7.886 (3.820-14.809)	0.371 (0.263-0.457)	27.285	25.030	0.593
School															
Rooms[b]	45	52	52	3.208 (3.251)	3.720 (3.102)	0.453 (0.287)	2.340 (2.166)	2.906 (1.964)	0.407 (11.515)	2.469 (1.154-3.746)	2.619 (1.939-4.398)	0.371 (0.354-0.447)	9.597	10.956	1.007
Playgrounds	26	26	26	3.682 (10.899)	3.781 (10.781)	0.389 (0.130)	1.194 (2.999)	1.376 (2.780)	0.373 (1.322)	0.867 (0.721-1.074)	0.999 (0.929-1.120)	0.388 (0.366-0.402)	11.156	11.210	0.428
Parks	68	67	68	1.495 (5.934)	1.656 (5.948)	0.282 (0.098)	0.610 (2.433)	0.815 (2.121)	0.268 (1.363)	0.584 (0.344-0.757)	0.709 (0.543-0.975)	0.216 (0.211-0.368)	3.722	3.769	0.419

SD: standard deviation; GM: geometric mean; GSD: geometric standard deviation; IQR: interquartile range; P95: 95th percentile; We provide magnetic flux density values; Measurement range of the probe: from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields respectively; [a]Five readings were missed ; [b]Calculations have been made based on rooms and not as a mean of school; [c]There were some missing readings for the 100 Hz span of electric fields, mainly due to human errors; Measurement range of the probe: from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields respectively.

Table 3

Correlation between electric and magnetic fields based on spot measurements

		50 Hz	5-100 Hz	12Hz-1 kHz		1.2 kHz-100 kHz	
	N^a	rho	rho	N^a	rho	N^a	rho
Homes	129	-0.059	-0.107	742	0.086	742	**0.724****
Living room	64	-0.044	-0.103	369	0.127	369	**0.743****
Child´s bedroom	65	-0.074	-0.103	372	0.037	372	**0.705****
Schools							
Classrooms	45	-0.189	-0.229	260	0.077	259	**0.647****
Playgrounds	26	0.283	0.136	26	0.232	26	0.285
Parks	67	**0.268***	**0.288***	67	**0.357***	67	**0.752****

rho: Spearman´s rank correlation coefficient; ^{a}Calculations were based on individual spot measurements, which consisted of the average of 32 consecutive readings; All significant values are in bold; *p value<0.05; **p value <0.001

Most of the participants lived in buildings built after 1990 (59.8%). Regarding school classrooms, in 40 % of them teachers reported whiteboard use (detailed information is provided in Supplementary Tables 3 and 5). Of all the explanatory variables considered, only building year of the home, use of electronic whiteboards at school and overhead power lines (30-13.2 kV) within 200 meters from parks were associated with the ELF-MF exposure levels encountered (Supplementary Table 5). Homes built before 1990 were associated with somewhat higher magnetic field exposure over 24 hours (mean±sd/median: 0.019±0.011/0.015 µT) than those built after 1990 (mean±sd/median: 0.018±0.019/0.013 µT) (p = 0.037). School classrooms in which electronic whiteboards were used regularly were associated with slightly higher magnetic field exposure over 24 hours (mean±sd/median: 0.019±0.013/0.015 for schools that use whiteboards and 0.017±0.017/0.012 for schools that don´t use whiteboard; p= 0.047). The proportion of measurement sites with power lines and transformers are specified in Supplementary Table 2. We did not observe any clear differences in average ELF-MF exposures (24 hours indoors and 20 minutes outdoors) as a function of the presence or absence of any of these sources in the vicinity of our measurement sites in homes and schools but we encountered higher exposure levels in parks with overhead power lines (30-13.2 kV) at a distance of 200 meters (p= 0.018).

In this study, based on data obtained from the questionnaires, the children spent a median of 16 hours at home, 5.5 hours in school buildings, 1 hour in school playgrounds and 1.5 hours in parks. Use of this time pattern for the calculation of TWAs yields mean, median and 90th percentile values for the magnetic (calculated from 24-hour or 20-minute measurements data) and electric (calculated from 1 kHz span spot measurement data) fields of: 0.018, 0.015 and 0.025 µT and 7.56, 6.93 and 13.30 V/m respectively. If the children enrolled in our study would be classified regarding exposure in three groups (below median, between median and 90th percentile, and greater than or equal to the 90th percentile), there would be moderate (Cohen κ= 0.58) and substantial (Cohen κ= 0.76) agreement between their classification based on home exposure only and calculated TWA estimates based on all settings (homes, schools and parks) for magnetic and electric fields respectively (Supplementary Figure 2).

DISCUSSION

We performed measurements of ELF and IF electric and magnetic fields in multiple settings where children tend to spend most of their time. The ELF-MF levels encountered were low (with IQRs for the different settings in a range from 0.01 to 0.03 µT) and similarly low MF levels were found in the IF range. IQRs of ELF-EF levels were between 1 and 15 V/m for indoor settings and between 0.3 and 1 V/m for outdoor settings, while IQRs of IF-EF levels ranged from 0.2 to 0.5 V/m. All exposure levels were well below national and international regulations [23,24]. The correlation between magnetic and electric field strength was generally weak (though moderate for IF outdoors). The THD was higher for magnetic fields (median; 38-52% between settings) than for electric fields (median; 5-19% between settings).

Strengths of our study include the characterization of exposure in places where children tend to spend most of their time. While several studies have investigated children's exposure to ELF-MF [21,25–32], studies focused on electric field exposures, or exposures in the IF range are scarce.

Our measurement device (EHP-50D, Narda) [33] was calibrated prior to the study, and it has lower quantification limit and a higher resolution than other devices frequently used in ELF-MF exposure surveys (quantification limits for magnetic field: 0.3 nT for EHP-50D and between 10 nT and 100 nT for other devices; quantification limits for electric fields: 0.005 V/m for EHP-50D and between 0.3 and 10 V/m for other devices [34,35]. Although we found very low exposure levels, we were always able to obtain readings above the quantification limit in all settings. In addition, since the device allows either broadband or narrowband measurements, it enabled us to check the contribution of specific frequencies in relation to other specific frequency bands, as we did for the THD calculation. Some studies researching ELF-MF have paid more attention to the fundamental frequency (50 Hz in Europe, 60 Hz in North America and Brazil)

[36] than to the harmonics and few studies have reported data on this matter [37–40]. Nowadays, most modern electrical equipment use electronics for power regulation instead of transformers. As a consequence, the frequency content of the daily magnetic field exposure has changed mainly by adding odd harmonics [4]. Single-frequency emissions have become rare and simultaneous emissions of series of harmonics common, increasing the importance of spectrally-weighted measurements [41]. In the present study, IQRs of THD for magnetic and electric fields were 26-75% and 3-34% respectively, quite high compared to values reported by Bowman et al.(2000) [37] and Khan and Silva (2010) [39], particularly given that the latter authors consider fields up to 400 kHz. For IF fields, we did not identify any dominant frequencies which is probably due to different sources that contribute different dominant frequencies [10]. Correlation between ELF-MF and ELF-EF was very low in our study, especially indoors, in line with previous assessments [42]. This result emphasizes the relevance of measuring both types of fields separately, since it is not possible to predict one from the other.

Limitations of our study relate to the lack of longer-term measurements of outdoor magnetic fields (limited to 20-minute measurements), and indoor and outdoor electric fields. Regarding 24-hour measurements of ELF-MF, the ARIMMORA project found that a 24-hour period was sufficient to validly characterize longer-term average exposure [25]. We measured ELF-MF for 24 hours in each indoor location, but due to time and financial constraints, it was not feasible to make such measurements for ELF-EF or IF fields, and hence, we are unable to explore possible patterns in exposure to these fields over time. Nevertheless, in contrast to ELF-MF, ELF-EFs do not arise from current flow, so should not depend on usage of appliances. In line with this, ELF-EF have previously been shown to vary little over 24 hours [43]. We have no knowledge of the temporal variability of IF fields, given the lack of previous assessments accounting temporal variability of these fields in general population settings.

In addition, although we only conducted measurements on homes of a subsample of the cohort, no differences were observed between participants with measurements and the rest of the cohort members.

Concerning shielding elements, these can be relevant when assessing electric field strength. Although we did not collect information on those elements during the field work, measurements were not taken in close proximity to any element that could disturb the readings.

With regards to short-term spot measurements of MFs in homes, we only performed all measurements (in the center and four corners) in around two-thirds (64%) of cases, while in the other third (36%), we just took measurements in the center of each room. Based on homes with full measurements, however, Spearman's correlation coefficients between center and corner readings were high: 0.78 for the 1 kHz magnetic fields and 0.84 for the 100 kHz magnetic fields, and hence, center-only spot measurements can be considered a good proxy for average exposure in rooms (Table 2).

Unfortunately, data regarding exact location and characteristics of power lines or substations are not publicly available for our measurement area. While the local utility company kindly provided us with information regarding sources within a certain distance from our measurement sites, this information had relatively low spatial resolution and, in general, we were unable to assess whether the observed variation in exposure levels was associated with distance to these sources. In any case, there is already evidence that environmental sources only result in distinct differences in exposure when a strong source such as a high voltage power line or transformer is located very nearby [25,44]. We collected information on type of area, type of building, number of floors and building year based on the influence of these variables on magnetic field exposures in other studies [20–22], but, among them, in this study we only detected significant differences by building year. Data on in-house presence and usage of appliances can be collected with questionnaires [45], but exposure patterns display a very high spatial variability and therefore contributions of individual devices to exposure levels are difficult to capture. In addition, exposure from electric and household appliances may contribute less to children´s exposure than environmental sources, given that exposure from household appliances is very localized, strongly depends on the distance [46] and children usually do occasional use of these devices.

Overall, although there are a few ELF-MF exposure assessment studies, there is no standardized methodology for assessing ELF exposure and this hinders comparisons between studies. Even in our study, we conducted a combination of different types of measurements seeking to adequately characterize the exposure. Nevertheless, some general comparisons can be made, to facilitate the interpretation of our results.

The 24-hour ELF-MF exposure levels we observed in homes and classrooms were low [21,25,47] or very low [26] compared to those found in other studies. Tomitsch et al., (2010) also reported very low exposures (a mean value of 0.06 μT at night, with bedroom measurements from 10 pm to 6 am), though they found exposures exceeding 0.1 μT in 2.3% of homes [48]. Low exposures have also been found in France (24-hour personal measurements, 40-800 Hz) and Germany (fixed 24-hour measurements in homes, 50 Hz), similar to ours (mean and median 0.09 and 0.02 µT in France and 0.046 and 0.031 µT in Germany) [20,21]. In addition, in the French and German studies with samples of 977 children and 1314 homes respectively, 86.4% and 91.4% of measurements were below 0.1 µT. With regard to ELF-EFs, we found higher exposure levels and higher spatial variability in homes than parks. ELF-EF median values in our spans were higher than those reported by Calvente et al. (2014) in homes [26] (median value 3.7 V/m for 15 Hz-100 kHz bandwidth) and Huang et al., (2013) in schools [47] (median value 0.15 V/m for 50 Hz frequency). Our EF levels are close to those of Huang et al. for IFs, but, on the other hand, they provide results combined for indoors and outdoors. Higher indoor ELF-EF were observed in a study performed in Austria [49].

Overall, we are aware of only few studies that have performed spot measurements or longer-term exposure measurements outdoors [50–53] or in schools [29,47,54–56], and among them only three included measurements in school playgrounds. Previous studies providing outdoor data found higher ELF-MF levels than we did with average exposures ranging from 0.11 µT in Spain (40-400 Hz bandwidth) to 0.90 µT in Sweden during winter (40-800 Hz bandwidth), both one order of magnitude larger than our results, and we do not have a clear explanation for this observed difference. In contrast, our exposures were similar to those reported from school playgrounds in Oviedo (mean of 0.016 µT and median of 0.012 µT at 50 Hz) and Valladolid (5 Hz-100 kHz bandwidth, mean of 0.280 µT) but lower than exposures observed in Barcelona (mean of 0.034 µT and median of 0.007 µT at 50 Hz), all in Spain [54,56].

There is limited knowledge regarding typical levels of exposure to electric fields, especially in the IF range [57,58]. In general, our measured IF-MF and IF-EF field levels were very similar across the different settings, including playgrounds and parks, which would be expected to be further away from any potential sources like induction hobs, antitheft alarms, computer screens or compact fluorescent lighting. Our parks were in relatively close proximity to buildings, as parks were usually in squares located in residential areas, and this could possibly explain why we found some low-level and similar exposures in these settings to those found indoors. Nevertheless, it is worth noting that the selected frequency band (1.2 kHz-100kHz) covers only a part of the total IF bandwidth. In addition, when conducting the measurements, we set all the appliances to “normal use” and measurements were not taken close to them. A recent study assessed IF exposure in homes of volunteers (in the 1.2-100 kHz frequency band) and reported higher magnetic field levels (geometric mean: 0.063 µT) and similar electric field levels when the devices were switched off (geometric mean: 0.4 V/m when the devices were switched off) than us [10]. They performed measurements under two scenarios: with all the appliances switched off and with all of them switched on. They found differences (170%) for IF-EF exposure levels between both scenarios, while the emissions of IF-MF were similarly low under both conditions and considered as background. Based on their results, we wouldn't expect to detect much more emissions of IF-MF indoors if we would have all appliances switched on and the differences between indoor and outdoor exposure would remain similar.

Overall, great efforts have been put into evaluating the contribution of various sources to magnetic field exposures to personal exposure levels. This is more complicated to perform for electric field exposures: since the human body perturbs electric fields, unperturbed personal measurements are not possible [5]. We attempted to overcome this problem by performing spot measurements in many different settings, to allow the estimation of TWA exposures depending on location and time spent in each location by the children in our cohort. Based on our results, while assessing ELF-MF exposure from home measurements only without incorporating exposure received in other environments would lead to misclassification (Cohen κ= 0.58), performing just home measurements of ELF-EFs could be considered a reasonable proxy for children´s overall exposure to ELF-EF (Cohen κ= 0.76).

All ELF-MF data presented in this study are considered background exposure, and the level is well below the threshold of 0.3-0.4 μT that has been associated with increased risks of childhood leukemia [59]. We consider further research on ELF-EF and IF exposures necessary for future epidemiological studies. WHO has specifically called for further research on IF, given the lack of data on this frequency range [13–15].

CONCLUSIONS

We performed extensive measurements to characterize exposure to ELF and IF magnetic and electric fields in environments where children spend most of the day (homes, schools and parks). Children of INMA-Gipuzkoa cohort are exposed to very low levels of ELF-MFs, but similar ELF-EF levels to those reported in most published studies. Very low ELF-MF levels were observed in all settings, although slightly lower exposures were found in parks and playgrounds than homes and classrooms. Somewhat higher exposures occurred at home and during the evening. ELF-EF levels were higher in homes and lower in parks. We also present data on IF exposure levels, but the lack of previous assessments of this frequency range means that there is barely equivalent data with which to compare our results. Interestingly, exposure levels of IF were similar in all settings. With the introduction of further appliances using IF, it may be relevant to explore the contribution of IF to overall EMF exposure in the future and to assess potential health effects of that exposure.

ACKNOWLEDGMENTS

We would like to thank all INMA families for their active collaboration, this being essential for achieving the objectives of the INMA Project. We would also like to thank all the INMA-Gipuzkoa researchers, who helped in field work and data collection when needed, especially Alain Noriega. A full list of researchers can be found at:
http://www.proyectoinma.org/cohorts/gipuzkoa/en_membres-gipuzkoa.html
MG would like to thank the Department of Education, Language Policy and Culture of the Government of the Basque Country for a predoctoral research training grant.

Funding

This work has been funded by grants from the Spanish Carlos III Health Institute (FIS-FEDER PI13/02187) and the councils of the study region of Gipuzkoa.

Ethical declaration

Prior to children's inclusion in the study, their legal guardians provided written informed consent. The research has been performed in accordance with the Spanish Law 14/2007 on Biomedical Research and the ethical principles of the Declaration of Helsinki. This work has been approved by the ethical committee of the Basque Country (CEIC-E).

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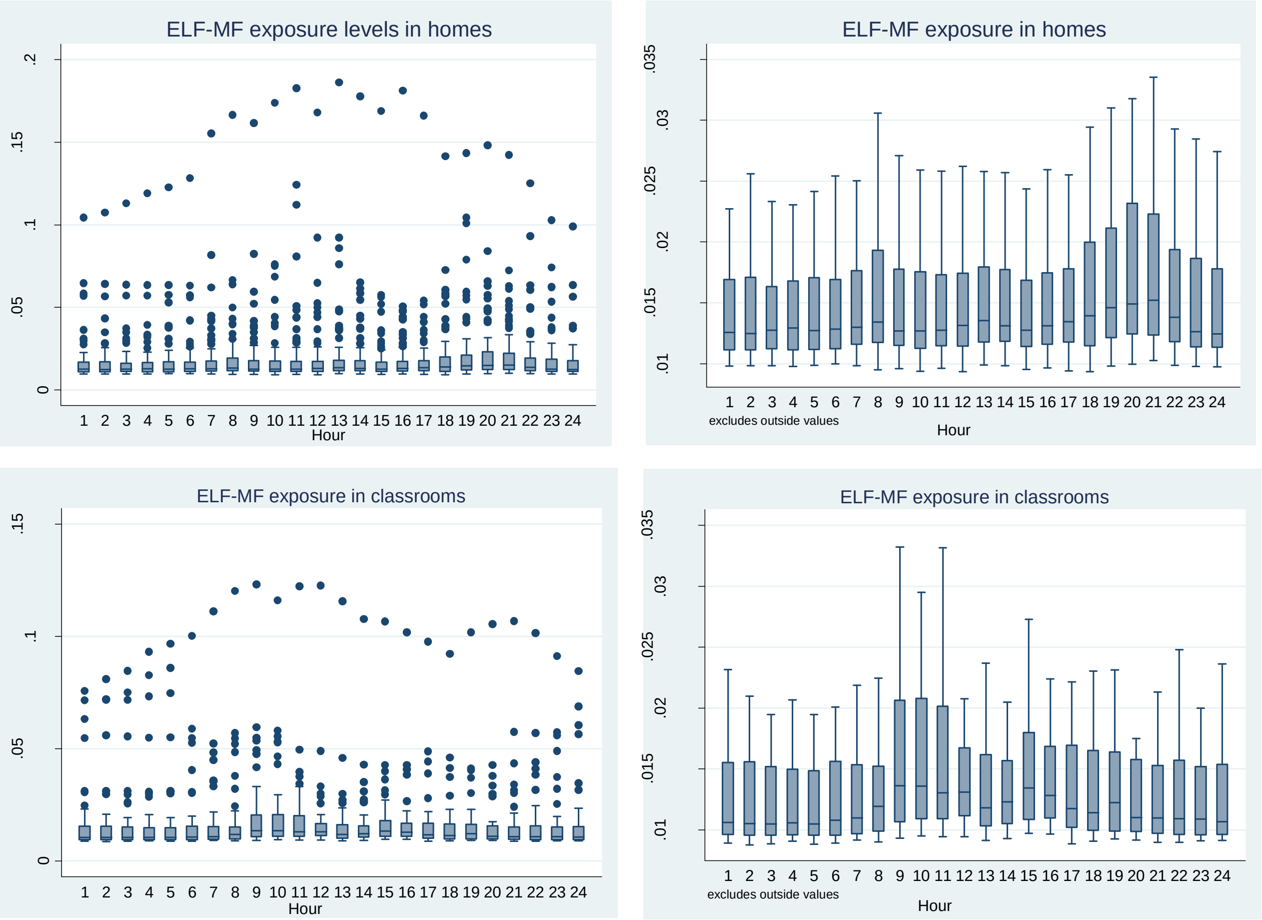
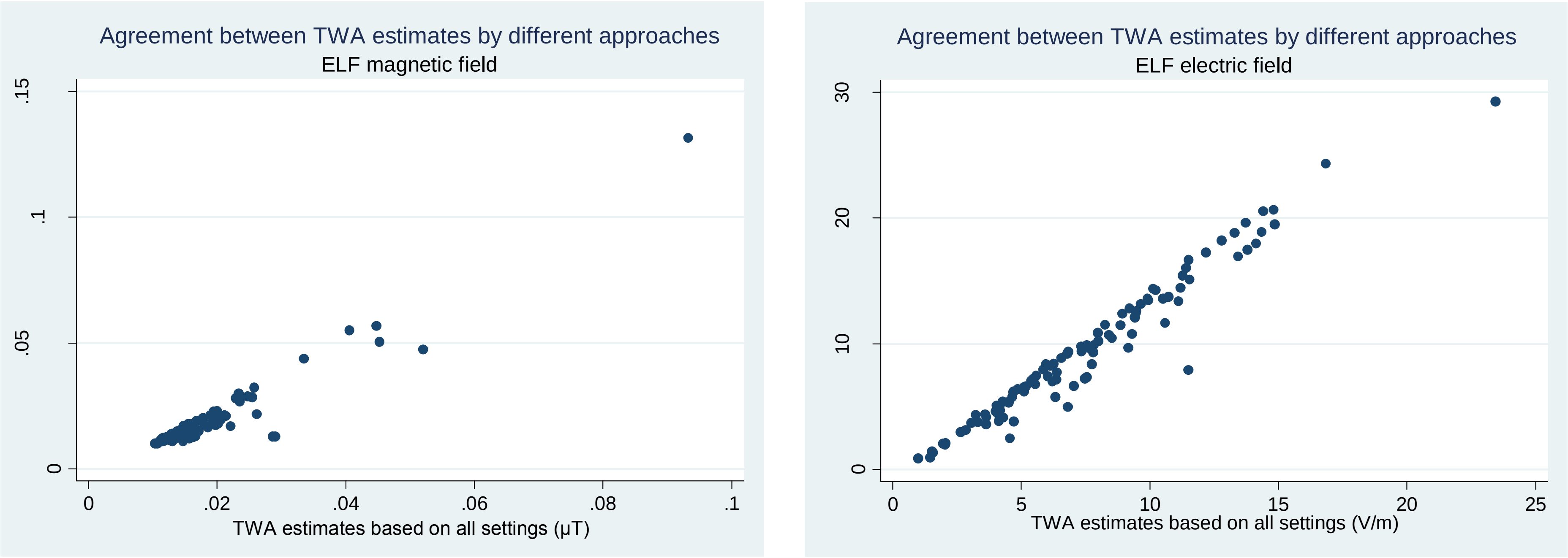
SUPPLEMENTARY MATERIAL



Supplementary Figure 1: ELF-MF exposure levels over 24 hours in homes and schools. ELF-MF: extremely low frequency magnetic fields. We provide magnetic flux density values; Calculations have been made using the hourly mean values in each setting; Outliers were excluded in the two graphs on the right; Hour “1” refers to measurements performed between 1:00 and 1:59 and analogously for the rest of the hours; Measurement range of the probe: from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields respectively.



Supplementary Figure 2: Agreement between TWA estimates based on all settings (homes, schools, parks) and based on home exposures only. TWA: time-weighted average; ELF: extremely low frequency; for the magnetic field we provide magnetic flux density values; TWA for magnetic field was calculated using 20-minutes measurements for outdoors and 24-hour measurements for indoors; TWA for electric field was calculated using spot measurements.

Supplementary Table 1. Measurement procedure: spot and fixed longer-term measurements of extremely low frequency (ELF) and intermediate frequency (IF) electromagnetic fields

	N	Field	Frequency range	Duration (time interval)	Measurement site[a]
INDOOR					
Homes & schools					
Bedroom and living room/two classrooms	104 & 54	EF/MF	5-100 Hz	Spot measurement (32 sampling average)	Center
	104 & 54	EF/MF	12 Hz-1 kHz	Spot measurement (32 sampling average)	Center & four corners
	104 & 54	EF/MF	1.2-100 kHz	Spot measurement (32 sampling average)	Center & four corners
	103 & 54	MF	6-500 Hz	24 h (30 s)	Center
OUTDOOR					
Public parks/playgrounds & school playgrounds	105 & 26	EF/MF	5-100 Hz	Spot measurement (32 sampling average)	Center
	105 & 26	EF/MF	12 Hz-1 kHz	Spot measurement (32 sampling average)	Center
	105 & 26	EF/MF	1.2-100 kHz	Spot measurement (32 sampling average)	Center
	105 & 26	MF	6-500 Hz	20 min (30 s)	Center

EF: electric fields; MF: magnetic field (we measured magnetic flux density); 2 classrooms of each of the 26 schools where measured; [a]All measurements were made at 1.1 m above ground and at 1.4 m from walls in the case of corners

Supplementary Table 2
Details of information requested to energy distribution companies: sources and distance to our measurement sites

Source	Distance to homes	Distance to schools/parks	N (%) of homes[b]	N (%) of schools[b]	N (%) of parks[b,c]
Very high voltage power line (132 kV)	150 m	200 m	-	-	6 (8.7)
High (30 kV) and medium (13.2 kV) voltage power lines[a]	150 m	200 m	-	-	-
Overhead			19 (18.3)	8 (30.8)	8 (11.6)
Underground			68 (65.4)	12 (46.2)	47 (68.1)
Both over- and underground			44 (42.3)	17 (65.4)	44 (63.8)
Distribution Transformer Substations with very high voltage (from 132 kV to 30 kV)	150 m	200 m	-	-	-
Distribution Transformer Substations (from 30 kV to 13.2 kV)	75 m	125 m	-	-	1 (1.4)
Transformer Stations (from 13.2 kV to 250-300 V)	50 m	100 m	28 (26.9)	16 (61.5)	54 (78.3)

kV: kilovolt; m: meters; [a]For these lines it was necessary to specify whether they were overhead, underground or both overhead and underground; [b]Number and proportion with at least one source of each type; [c]For parks, we only obtained information on proximity to outdoor sources for 69 out of 105 parks where measurements were taken; we also checked whether there were any very high voltage power lines of transport (250-300 kV) in our area but it was not the case.

Supplementary Table 3. Characteristics of the subsample with measurements on their homes and of the rest of the cohort members

	Sample with measurements[a] (n=104) n (%)	Sample without measurements[b] (n=293) n (%)	p[c]
Sex of the child			
Female	47 (45.2)	153 (52.2)	0.218
Male	57 (54.8)	140 (47.8)	
Variables of the mother			
Age of the mother at birth			
<25	0 (0.0)	4 (1.4)	0.069
25-29	30 (28.8)	92 (31.4)	
30-34	60 (57.7)	143 (48.8)	
>35	14 (13.5)	54 (18.4)	
Country of origin			
Spanish	103 (99.0)	284 (96.9)	0.465
Non-Spanish	1 (1.0)	9 (3.1)	
Social class			
Non-manual	72 (69.2)	177 (60.4)	0.110
Manual	32 (30.8)	116 (39.6)	
Study level[d]			
Primary school	7 (6.7)	33 (11.3)	0.065
Secondary school	31 (29.8)	111 (38.2)	
University-level	66 (63.5)	147 (50.5)	
Type of area[e]			
Rural	6 (5.8)	37 (12.6)	0.946
Semi-urban	46 (44.2)	114 (38.9)	
Urban	52 (50.0)	142 (48.5)	
Number of children[f]			
1	25 (24.0)	84 (28.8)	0.354
>1	79 (76.0)	208 (71.2)	
Outdoor sources[g]			
Very high voltage (132 kV) power lines within 150 meters			
None	104 (100.0)	289 (99.0)	0.299
Any	0 (0.0)	3 (1.0)	
High (30 kV) and medium (13.2 kV) voltage power lines within 150 meters			
Overhead			
None	85 (81.7)	247 (84.6)	0.497
Any	19 (18.3)	45 (15.4)	
Underground			
None	36 (34.6)	112 (38.4)	0.498
Any	68 (65.4)	180 (61.6)	
Both over- and underground			
None	60 (57.7)	150 (51.4)	0.267
Any	44 (42.3)	142 (48.6)	
Transformer Stations (from 13.2 kV to 250-300 V) within 50 meters			
None	76 (73.1)	194 (66.4)	0.212
Any	28 (26.9)	98 (33.6)	

Characteristics of the subsample with and without measurements were evaluated in order to assess representativeness of the subsample selected for the measurements; [a]Refers to families whose homes were measured; [b]Refers to families who continued participating in the INMA project during the 8 years old follow up, but whose homes were not measured, either because they were not selected for the subsample A or because they refused to have measured conducted in their homes; [c]Differences were tested by Chi square test. However, when expected counts were below 5 Fisher's exact test was used; [d]Two mothers did not answer; [e]Population above 10,000 inhabitants was considered urban, between 2,000 and 10,000 semi-urban and below 2,000 rural; [f]One mother did not answer; [g]There is no available information for one home

Supplementary Table 4
Total harmonic distortion (THD) in different settings

		N[a]	Median		IQR	
			THD[b]	Noise/power frequency[c]	THD[b]	Noise/power frequency[c]
	Magnetic fields (µT)					
Homes		743	0.50	0.52	0.31-0.71	0.32-0.73
	Living room	371	0.48	0.94	0.30-0.68	0.53-1.30
	Child room	372	0.52	1.03	0.34-0.75	0.60-1.43
School						
	Rooms	260	0.38	0.77	0.27-0.53	0.50-1.11
	Playgrounds	26	0.44	1.01	0.30-0.52	0.81-1.35
Parks		67	0.42	1.09	0.26-058	0.66-1.46
	Electric fields (V/m)					
Homes		1038	0.06	0.06	0.03-0.10	0.04-0.10
	Living room	519	0.07	0.09	0.04-0.11	0.06-0.14
	Child room	519	0.05	0.07	0.03-0.09	0.05-0.12
School						
	Rooms	260	0.13	0.16	0.10-0.2	0.12-0.27
	Playgrounds	26	0.10	0.23	0.08-0.26	0.14-0.71
Parks		67	0.19	0.48	0.10-0.34	0.25-0.92

IQR: interquartile range; we provide magnetic flux density values; [a]This refers to the total number of spot measurements. Number of sites per setting is specified in Tables 1 and 2; [b]Exposures from harmonics up to 300 Hz were divided by exposure obtained for 50 Hz peak; [c]Exposures from 12 Hz to 1 kHz, excluding contribution of 50 Hz peak, were divided by exposure from 50 Hz peak; Measurement range of the probe: from 0.3 nT to 100 µT and from 5 mV/m to 1 kV/m, for magnetic and electric fields respectively.

Supplementary Table 5. ELF magnetic field levels by considered explanatory variables (building year, type of building, type of area and transformers and power lines in the vicinity)

	n (%)	Mean (SD)	Median (IQR)	p
Homes				
Construction year of the building				
≤1990[a]	39 (40.2)	0.019 (0.011)	0.015 (0.013-0.019)	**0.037**
>1990	58 (59.8)	0.018 (0.019)	0.013 (0.012-0.018)	
Type of dwelling				
Detached/semi detached	15 (14.6)	0.024 (0.034)	0.013 (0.012-0.020)	0.968
Multiple storey building with 2-8 apartments	26 (25.2)	0.016 (0.005)	0.015 (0.012-0.019)	
Multiple storey building with more than 8 apartments	62 (60.2)	0.018 (0.011)	0.014 (0.012-0.019)	
Type of area[b]				
Rural	6 (5.8)	0.024 (0.014)	0.020 (0.015-0.029)	0.115
Semi-urban	45 (43.7)	0.017 (0.009)	0.013 (0.012-0.019)	
Urban	52 (50.5)	0.019 (0.020)	0.014 (0.012-0.018)	
High (30 kV) and medium (13.2 kV) voltage power lines within 150 meters				
Overhead				
None	84 (81.6)	0.018 (0.009)	0.014 (0.012-0.019)	0.824
Any	19 (18.4)	0.023 (0.030)	0.014 (0.013-0.020)	
Underground				
None	36 (35.0)	0.020 (0.022)	0.014 (0.013-0.020)	0.386
Any	67 (65.0)	0.018 (0.010)	0.014 (0.011-0.019)	
Both over- and underground				
None	59 (57.3)	0.020 (0.019)	0.014 (0.012-0.019)	0.598
Any	44 (42.7)	0.017 (0.007)	0.015 (0.013-0.019)	
Transformer Stations (from 13.2 kV to 250-300 V) within 50 meters				
None	75 (72.8)	0.019 (0.017)	0.014 (0.012-0.019)	0.985
Any	28 (27.2)	0.017 (0.008)	0.015 (0.012-0.019)	
Schools				
Rooms[c]				
Television (regular use)[d]				
No	44 (88.0)	0.018 (0.016)	0.012 (0.010-0.017)	0.258
Yes	6 (12.0)	0.015 (0.008)	0.010 (0.010-0.024)	

Supplementary Table 5 (continued)

	n (%)	Mean (SD)	Median (IQR)	p
Computers (regular use)				
No	4 (7.7)	0.032 (0.022)	0.033 (0.012-0.053)	0.139
Yes	48 (92.3)	0.016 (0.014)	0.012 (0.010-0.016)	
Projectors (regular use)[d]				
No	20 (40.0)	0.017 (0.013)	0.010 (0.010-0.017)	0.172
Yes	30 (60.0)	0.018 (0.017)	0.012 (0.011-0.017)	
Electronic whiteboards (regular use)[d]				
No	30 (60.0)	0.017 (0.017)	0.012 (0.010-0.015)	**0.047**
Yes	20 (40.0)	0.019 (0.013)	0.015 (0.010-0.022)	
High (30 kV) and medium (13.2 kV) voltage power lines within 200 meters				
Overhead				
None	36 (69.2)	0.017 (0.016)	0.012 (0.010-0.017)	0.952
Any	16 (30.8)	0.017 (0.013)	0.012 (0.010-0.017)	
Underground				
None	28 (53.8)	0.017 (0.011)	0.013 (0.010-0.017)	0.521
Any	24 (46.2)	0.018 (0.019)	0.011 (0.010-0.017)	
Both over- and underground				
None	18 (34.6)	0.016 (0.013)	0.011 (0.010-0.015)	0.453
Any	34 (65.4)	0.018 (0.016)	0.013 (0.010-0.018)	
Transformer Stations (from 13.2 kV to 250-300 V) within 100 meters				
None	20 (38.5)	0.021 (0.023)	0.011 (0.010-0.016)	0.331
Any	32 (61.5)	0.015 (0.001)	0.014 (0.011-0.017)	
Playgrounds				
High (30 kV) and medium (13.2 kV) voltage power lines within 200 meters				
Overhead				
None	18 (69.2)	0.014 (0.008)	0.011 (0.009-0.012)	0.196
Any	8 (30.8)	0.016 (0.008)	0.012 (0.010-0.023)	
Underground				
None	14 (53.8)	0.015 (0.008)	0.012 (0.010-0.017)	0.374
Any	12 (46.2)	0.014 (0.008)	0.011 (0.010-0.012)	

Supplementary Table 5 (continued)

	n (%)	Mean (SD)	Median (IQR)	p
Both over- and underground				
None	9 (34.6)	0.011 (0.002)	0.011 (0.010-0.012)	0.426
Any	17 (65.4)	0.016 (0.010)	0.011 (0.010-0.026)	
Transformer Stations (from 13.2 kV to 250-300 V) within 100 meters				
None	10 (38.5)	0.012 (0.005)	0.011 (0.010-0.013)	0.551
Any	16 (61.5)	0.016 (0.009)	0.011 (0.010-0.023)	
Parks[e]				
Very high voltage power line (132 kV) within 200 meters				
None	63 (91.3)	0.020 (0.021)	0.012 (0.010-0.016)	0.512
Any	6 (8.7)	0.018 (0.014)	0.013 (0.011-0.025)	
High (30 kV) and medium (13.2 kV) voltage power lines within 200 meters				
Overhead				
None	61 (88.4)	0.019 (0.021)	0.011 (0.010-0.017)	**0.018**
Any	8 (11.6)	0.022 (0.018)	0.016 (0.014-0.021)	
Underground				
None	22 (31.9)	0.014 (0.009)	0.012 (0.010-0.015)	0.253
Any	47 (68.1)	0.022 (0.023)	0.012 (0.010-0.021)	
Both over- and underground				
None	25 (36.2)	0.022 (0.025)	0.012 (0.010-0.022)	0.474
Any	44 (63.8)	0.018 (0.017)	0.012 (0.010-0.016)	
Distribution Transformer Substations (from 30 kV to 13.2 kV) within 125 meters				
None	68 (98.6)	0.019 (0.018)	0.012 (0.010-0.016)	-
Any	1 (1.4)	-	-	
Transformer Stations (from 13.2 kV to 250-300 V) within 100 meters				
None	15 (21.7)	0.020 (0.023)	0.010 (0.010-0.012)	0.101
Any	54 (78.3)	0.020 (0.019)	0.012 (0.010-0.017)	

ELF: extremely low frequency; SD: standard deviation; IQR: interquartile range; p: p value; kV: kilovolt; We provide magnetic flux density values; [a]Some participants did not know building year; [b]Population above 10,000 inhabitants was considered urban, between 2,000 and 10,000 semi-urban and below 2,000 rural; [c]We performed the analysis based on classrooms (52); [d]Two teachers were not able to say if the use was regular or not; [e]For parks, we only obtained information on proximity to outdoor sources for 69 out of 105 parks where measurements were taken, so that percentages were calculated based on those 69 parks; significant p values are represented in bold.

Children's exposure assessment of radiofrequency fields: comparison between spot and personal measurements

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Under review (Second revision)

ABSTRACT

Introduction

Radiofrequency (RF) fields are widely used and, while it is still unknown whether children are more vulnerable to this type of exposure, it is essential to explore their level of exposure in order to conduct adequate epidemiological studies. Personal measurements provide individualized information, but they are costly in terms of time and resources, especially in large epidemiological studies. Other approaches, such as estimation of time-weighted averages (TWAs) based on spot measurements could simplify the work.

Objectives

The aims of this study were to assess RF exposure in the Spanish INMA birth cohort by spot measurements and by personal measurements in the settings where children tend to spend most of their time, i.e., homes, schools and parks; to identify the settings and sources that contribute most to that exposure; and to explore if exposure assessment based on spot measurements is a valid proxy for personal exposure.

Methods

When children were 8 years old, spot measurements were conducted in the principal settings of 104 participants: homes (104), schools and their playgrounds (26) and parks (79). At the same time, personal measurements were taken for a subsample of 50 children during 3 days. Exposure assessment based on personal and on spot measurements were compared both in terms of mean exposures and in exposure-dependent categories by means of Bland-Altman plots, Cohen's kappa and McNemar test.

Results

Median exposure levels ranged from 29.73 (in children's bedrooms) to 200.10 µW/m^2 (in school playgrounds) for spot measurements and were higher outdoors than indoors. Median personal exposure was 52.13 µW/m^2 and median levels of assessments based on spot measurements ranged from 25.46 to 123.21 µW/m^2. Based on spot measurements, the sources that contributed most to the exposure were FM radio, mobile phone downlink and Digital Video Broadcasting-Terrestrial, while indoor and personal sources contributed very little (altogether <20%). Similar distribution was observed with personal measurements.

There was a bias proportional to power density between personal measurements and estimates based on spot measurements, with the latter providing higher exposure estimates. Nevertheless, there were no systematic differences between those methodologies when classifying subjects into exposure categories. Personal measurements of total RF exposure showed low to moderate agreement with home and bedroom spot measurements and agreed better, though moderately, with TWA based on spot measurements in the main settings where children spend time (homes, schools and parks; Kappa = 0.49).

Conclusions

Exposure assessment based on spot measurements could be a feasible proxy to rank personal RF exposure in children population, providing that all relevant locations are being measured.

Keywords: Exposure assessment; electromagnetic fields; radiofrequencies; children

Abbreviations

RF: Radiofrequency; TWA: time-weighted averages; INMA: Environment and childhood (from INfancia y Medio Ambiente) cohort; DVB-T: Digital Video Broadcasting-Terrestrial; LOQ: limit of quantification; DECT: Digital Enhanced Cordless Telecommunications; Uplink: Mobile phone uplink; Downlink: Mobile phone downlink

Highlights

- Children´s radiofrequency field levels and contribution of sources were assessed
- We contrasted exposure assessment based on spot and personal measurements
- Median exposures range: 29.73-236.31 μW/m^2; broadcast and downlink contributed most
- Proportional bias between assessment based on spot and personal measurements
- No systematical differences when classifying subjects in exposure-dependent groups

INTRODUCTION

Radiofrequency (RF) fields cover the frequency range between 10 MHz and 300 GHz and are mainly used for wireless communication purposes [1]. Sources of this type of electromagnetic field are growing and hence, there is a need for research into exposure assessment to guide the design of high quality epidemiological studies. In addition, further research on the characteristics of RF exposure, such as, assessment of exposure levels from emerging sources, quantification of personal exposure levels, and prospective studies of children and adolescents are considered high priority research needs by the World Health Organization (WHO) [2].

Whether children are more vulnerable than adults to RF exposure is still being discussed [3–5] but it is expected that present-day children and adolescents will have longer lifetime exposure than present-day adults. In addition, children's exposure profile, determinants of exposure and contribution of sources may vary from those of adults'.

To date, many epidemiological studies assessing health effects of RF exposure have been focused on specific sources, such as near-field sources (those whose radiation is contributing to people's exposure in the near field of the source, that extends to a distance of approximately 3 times the wavelength of the source) like mobile or cordless phones [6–13] (most of them considering self-reported use), and on distance to far-field sources (mobile phone base stations, television and radio antennas, whose radiation is contributing to people's exposure in the far field of the source) [14,15]. These indirect methods to assess exposure have limitations. Specifically, self-reporting of phone use has been proven to over- or under-estimate exposure sufficiently that it can lead to misclassification [9,16,17] and distance per se to far-field sources has been considered an inadequate surrogate for exposure assessment [18], showing moderate [19] or low [20] association with exposure from mobile phone base stations and also a very low correlation with personal measurements of total RF exposure [21].

Recently, efforts have been made to achieve more comprehensive exposure assessment. Many authors have tried to assess exposure by performing measurements (spot or personal) [22,23] or by using propagation simulations to predict such exposure [24,25]. Nevertheless, few studies have reported data on RF exposure on children or adolescents, combining exposure from near- and far-field sources [16]. Further, there is still no accepted standardized method for comprehensively assessing realistic exposure to RF fields of general public for epidemiological purposes. Personal measurements provide individualized information and consider temporal and spatial variations, but require substantially greater effort in terms of time and resources, especially in large epidemiological studies. Assessing exposure based on spot measurements may be an alternative and a proxy for personal exposure assessment.

Besides, while personal measurements may be more prone to random variability or to variability introduced by specific activities, spot measurements may be better replicated and thus they could better reflect longer-term exposure at the specific sites.

Although personal measurements have been found to be moderately correlated with simulated exposure [21,26,27], to our knowledge, there is a lack of studies assessing agreement between personal measurements and exposure assessment based on spot measurements in the main settings of the participants. Filling this gap in the literature could help to establish whether spot measurements can be used as a proxy for personal exposure levels, which is important, as this approach would simplify research and make it more feasible to cover larger populations.

The aims of this study were to assess RF exposure in the INMA-Gipuzkoa (*Infancia y Medio Ambiente*-Environment and childhood) birth cohort (www.proyectoinma.com) [28], by spot measurements and personal measurements in the settings where children tend to spend most of their time, i.e., homes, schools and parks; to identify the settings and sources that contribute most to that exposure; and to explore if exposure assessment based on spot measurements is a valid proxy for personal exposure.

MATERIAL AND METHODS

Study population

This study was embedded in the INMA-Gipuzkoa birth cohort which is located in the Basque Country and is part of a Spanish multicenter study [28].

The recruitment of mother-child pairs took place during the first antenatal visit (10-13 weeks of gestation) to the physician in the public referral hospital (Zumarraga hospital) between April 2006 and January 2008.

In total, 638 out of 993 mother-child pairs invited to participate met the inclusion criteria and agreed to be enrolled in the INMA-Gipuzkoa study. This study was conducted over the period 2014-2016, when the children reached 8 years of age, all cohort members were contacted; at that time, 397 children (62.2%) participated in the study.

Study procedure

Measurement devices

For measuring narrowband RF fields in the 87.5 MHz–6 GHz range, we used an ExpoM -RF 3 (hereinafter ExpoM) personal portable exposimeter (Fields at work, Zurich, Switzerland, 2017). This device measures exposure to 16 different frequency bands according to emissions from different main sources: FM Radio; Digital Video Broadcasting-Terrestrial (DVB-T); LTE 800 uplink and downlink (LTE 800 UL and LTE 800 DL respectively, used for 4G); GSM 900 uplink and downlink (GSM 900 UL and GSM 900 DL, used for 2G); GSM 1800 uplink and downlink (GSM 1800 UL and GSM 1800 DL, used for 2G/4G); Digital Enhanced Cordless Telecommunications (DECT); UMTS uplink and downlink (UMTS UL and UMTS DL, used for 3G); ISM 2.4 GHz (used for WiFi); LTE 2600 uplink and downlink (LTE 2600 UL and LTE 2600 DL, used for 4G); WiMax 3.5 GHz (used for wireless internet connection mainly in rural areas); and ISM 5.8 GHz (used for WiFi). Measurement ranges are displayed in Supplementary Table 1. This meter uses a three-axis isotropic antenna. The ExpoM was calibrated by the manufacturers prior to the measurement campaign, and every 6 months during the measurement campaign, to ensure good working conditions.

Measurement procedure

The procedure is explained in detail in a previous publication [30]. In brief, we conducted measurements in the settings where children spent most of their time, which are homes, schools and parks [31]. In the case of homes, measurements were taken in the living room and child´s bedroom in 104 households which were selected mainly on their availability since most of the mothers (386 of 397 contacted, 97.2%) agreed to measurements being taken in their home. All primary schools in the study area (N=26) were included in the measurement campaign and, in each school, the main playground and the two classrooms for each year group (second and third year of primary school) with the most of INMA students were chosen for performing the measurements. The parents selected the parks or other public spaces (hereinafter “parks”) where their children spent most of the time from a list of parks provided to them, and also ranked these places by the amount of time spent there. RF measurements were taken in a subset of all the parks in the study area (79/125, 63.2%), including those most frequently selected by parents.

The measurement procedure varied as a function of the environment (indoor or outdoor) (Supplementary Table 2). We performed three narrowband indoor measurements at the center at different heights and one in each of the four corners of each room (living rooms, children´s rooms and classrooms), and one outdoor measurement at the center of the spaces (playgrounds and parks). The device was held in a non-conducting tripod which was adjustable to the desired height. Mobile phone use was not allowed in the room where spot measurements were taken. In addition, in order to conduct personal measurements, a subsample of 50 children (randomly selected among the 104 with measurements at home) carried the exposimeter with them for 3 whole days with a measurement time-interval of 4-seconds. During the day the device was placed in a padded belt bag around their waist. At night, children placed the device on a flat non-metallic surface, as close as possible to their bed. In order to ensure that the battery of the device lasted, it had to be charged every night during sleeping-hours of the children.

All spot measurements were conducted from Monday to Friday (weekdays), with school measurements being performed during school-hours, while personal measurements could include weekend days, but captured exposure from at least one weekday.

Data handling and statistical analysis

No significant differences were identified regarding relevant characteristics (sociodemographic characteristics and variables concerning potential RF sources) between the subsample selected for personal measurements (two subjects were discarded due to problems with the device, n=48) and the whole subsample with in-home measurements (n=104) (Supplementary table 3); and between the subsample with in-home measurements and the full cohort [32]. The device provided data on electric fields. For each measurement, a variable number of readings were obtained as a function of the measurement time-interval set (4 s) and the duration of the measurement. We assigned values of half the limit of quantification (LOQ) to readings below this limit and the upper limit to readings above the upper range. Substitution methods of censored data are very used in the epidemiological literature [33]. Subsequently, data were converted to power density (µW/m^2), for the assessment of exposure. In the case of spot measurements and following the procedure described by Frei et al., the mean for each room and for each of the bands was calculated [21]. Similarly, mean of readings obtained in each outdoor setting was calculated. During personal measurements, while the participants charged the ExpoM, the battery cable acted as an antenna, resulting in an overestimation of FM radio exposure. This error was corrected by replacing data by median exposure values obtained under the same conditions, i.e., when the exposimeter was at home, but was not charging. Whether the device was charging was specified in the results output.

Most of the RF sources were categorized into groups in order to assess their contribution to the total exposure and the sum between sources was done in power density. Broadcast sources corresponded to FM radio and DVB-T bands. Mobile phone uplink (uplink) sums results for all uplink bands (ascendant union, from devices to the antenna), i.e., LTE 800, GSM 900, GSM 1800, UMTS and LTE 2600, and mobile phone downlink (downlink) all downlink bands (descendant union, from antenna to the devices), i.e., LTE 800 GSM 900, GSM 1800, UMTS and LTE 2600. For wireless internet connection we have only considered the 2.4 GHz band, given that harmonics generated by signals around 1800 and 900 MHz interfere in the readings of 5.8 GHz WiFi and given that other wireless internet sources (5.8 GHz band and WiMax 3.5 GHz) are rarely present (out of the 442 settings where we conducted measurements only 2.3 and 1.1% showed mean levels above LOQ for 5.8 GHz and 3.5 GHz, respectively). Those two internet bands were also excluded for the calculation of total exposure and the only wireless internet source considered was the 2.4 GHz band.

Differences between settings were checked by non-parametric Mann-Whitney U (indoor/outdoor) and Kruskal-Wallis (homes/classrooms/school-playgrounds/parks) tests because exposure levels did not show a normal distribution.

We employed several approaches based on spot measurements for assessing children’s RF exposure. On the one hand, we used average exposure levels measured in specific settings to estimate individual exposure as follows:

a) average exposure levels found in each home (including measurements in bedroom and living room) by spot measurements; herein, home measurements;

b) average exposure levels found in each bedroom by spot measurements; herein, bedroom measurements;

c) average exposure levels found in each living room by spot measurements; herein, living room measurements;

On the other hand, time-weighted averages (TWAs) were calculated for each participant taking into account hours spent at home, at school and in parks together with the exposure levels obtained by spot measurements in those settings. For this purpose, we used the information that parents reported in questionnaires regarding time spent in each setting, making different adjustments:

d) TWA based on considering the same number of hours spent in each setting for all the children (median value of the total hours reported by parents of all participants), adjusted to 24 hours, hereinafter, median TWA-adjusted;

e) TWA based on the number of hours that each child spent in the settings as reported by their parents adjusted to 24 hours, herein, own TWA-adjusted;

f) TWA based on the same procedure as “e”, but not adjusted to 24 hours; herein, own TWA-unadjusted.

Spearman correlations were calculated between personal measurements and each of the approaches. Agreement between the different approaches (taking personal measurements as the reference and considering all approaches as continuous variables) was assessed using Bland-Altman plots [34]. In addition, children were classified into three exposure categories (low, medium and high) with a cut off at median and 90th percentile based on their personal and spot measurements in correspondence to previous studies [21,35]. Agreement between group assignment using personal and spot measurements were compared by means of Cohen's kappa coefficient. Further, the McNemar test was used to assess whether there was a systematic difference between the results obtained with each approach compared to personal measurements.

Data were analyzed with Stata (version 14.1; StataCorp, College Station, TX, USA) and SPSS (version 19).

RESULTS

Exposure levels

Median exposures ranged from 29.73 (in children's bedrooms) to 200.10 µW/m^2 (in school playgrounds) for spot measurements (Table 1). The highest total exposure of 36.94 mW/m^2 was found for a school, an extreme outlier attributed to it having a radio antenna on the roof. The second highest spot measurement value was found in a park (14.81 mW/m^2), and in general terms, exposure levels were higher outdoors than indoors ($p<0.001$). In line with this, broadcast and downlink readings were higher outdoors ($p<0.001$). Uplink readings were more similar for indoor and outdoor measurements ($p=0.882$), and child´s rooms and school playgrounds were the settings with the lowest readings for this type of source. WiFi and DECT readings were higher indoors ($p<0.001$) and the latter was only notable in living rooms (mean±sd/median: 2.43±16.25/0.08 µW/m^2). Higher WiFi readings were found in homes (especially in living rooms; mean±sd/median 12.7±80.03/2.92 µW/m^2) than in classrooms (mean±sd/median 2.33±1.29/1.74 µW/m^2) ($p<.001$).

Median personal exposure was 52.13 µW/m^2 and median exposure for approaches based on spot measurements ranged from 25.46 to 123.21 µW/m^2 (Table 2).

Table 1. Descriptive statistics of total radiofrequency exposure levels by spot and personal measurements

	N	Mean (SD)	Geometric mean (GSD)	Median (IQR)	P90	Minimum	Maximum
Homes							
Child´s room	104	99.14 (162.44)	35.79 (4.33)	29.73 (13.06-111.33)	298.60	2.74	1034.68
Living room	104	195.69 (639.37)	54.30 (4.70)	51.60 (17.29-170.25)	315.28	2.75	6307.44
School							
Classrooms	26[a]	1535.77 (7222.74)	77.67 (6.19)	82.80 (21.44-184.31)	362.89	2.77	36942.15
Classrooms[b]	25[a]	119.51 (135.61)	60.69 (3.84)	81.10 (21.44-181.44)	224.87	2.77	603.22
Playground	26	255.62 (244.38)	157.34 (3.07)	200.10 (97.32-290.51)	655.86	9.28	950.74
Parks	78	623.31 (1895.78)	154.91 (4.36)	122.96 (47.98-364.58)	1349.06	12.88	14806.83
Personal measurements	48[c]	169.19 (720.70)	50.14 (3.09)	52.13 (24.87-84.17)	201.75	2.88	5042.77

All values are given in power density, μW/m^2; SD: standard deviation; GSD: geometric standard deviation; IQR: interquartile range; P95: 95th percentile; [a]Average of the two classrooms from each school; [b]Data for one school was omitted from this calculation, since it was an extreme outlier; [c]Two measurements out of 50 had to be omitted due to technical problems

Table 2. Descriptive statistics of children’s daily exposure estimates by different methodologies

	N[a]	Mean (SD)	Geometric mean (GSD)	Median (IQR)	P90	Minimum	Maximum
Personal measurements	48	169.19 (720.66)	50.14 (3.09)	52.13 (24.87- 84.17)	201.75	2.88	5042.77
Homes	48	183.62 (466.58)	56.02 (4.73)	77.76 (14.51-164.08)	360.91	3.50	3173.04
Bedroom measurements	48	115.08 (195.48)	37.82 (4.66)	25.46 (12.77-118.80)	329.23	2.74	1034.68
Living room measurements	48	252.15 (911.83)	55.25 (5.18)	51.34 (16.46-179.76)	295.21	2.82	6307.44
Median TWA-adjusted[b]	48	381.57 (1308.35)	120.63 (3.34)	123.21 (55.62- 215.08)	509.83	14.58	8941.53
Own TWA-adjusted[c]	47[d]	412.13 (1828.98)	91.75 (4.03)	105.86 (42.01-196.32)	518.23	1.45	12635.77
Own TWA-unadjusted[e]	47[d]	500.27 (2197.41)	118.99 (3.50)	119.56 (53.19-224.02)	530.58	15.47	15162.93

Calculations are performed only for the subsample with both personal and spot measurements; All values are given in power density (μW/m^2); TWA: time-weighted average; SD: standard deviation; GSD: geometric standard deviation; IQR: interquartile range; P95: 95th percentile; [a]Two out of 50 personal measurements had to be omitted due to technical problems; [b]based on spot measurements and on median hours reported by parents for each setting; [c]based on spot measurements and on hours reported by parents for each setting; [d]for one child, no questions were completed regarding number of hours spent in each setting; [e]based on spot measurements and hours specified in questionnaires by parents (total hours reported by each one, not necessarily 24 hours)

Regarding non-detects, a large proportion was found for some of the bands. Specifically, more than 75% of readings from all bands of uplink were below LOQ, and GSM1800 and LTE2600 uplink were the bands with more readings below LOQ. Proportion of non-detects in downlink bands depends greatly on the band, with just 10% and 26% of readings below LOQ for GSM900 and UMTS respectively, and more than 60% for the rest of the downlink bands. In the case of WiFi (ISM 2.4), FM radio and DVB-T up to 60%, 23% and 4% of all readings were below LOQ, respectively.

Contribution of the sources

The contributions of the different sources are displayed in Figure 1. In both types of measurements –spot and personal- FM radio, downlink and DVB-T were the sources that contributed most to exposure, although, in personal measurements, the contribution of broadcast frequencies was slightly lower and mobile phone uplink frequencies somewhat higher than in the spot measurements. In contrast, median contribution of mobile phone uplink to total RF exposure was 4.5% and WiFi, and cordless communication (DECT) altogether contributed less than 3%. The contribution of the sources followed a similar pattern across different settings (data not shown).

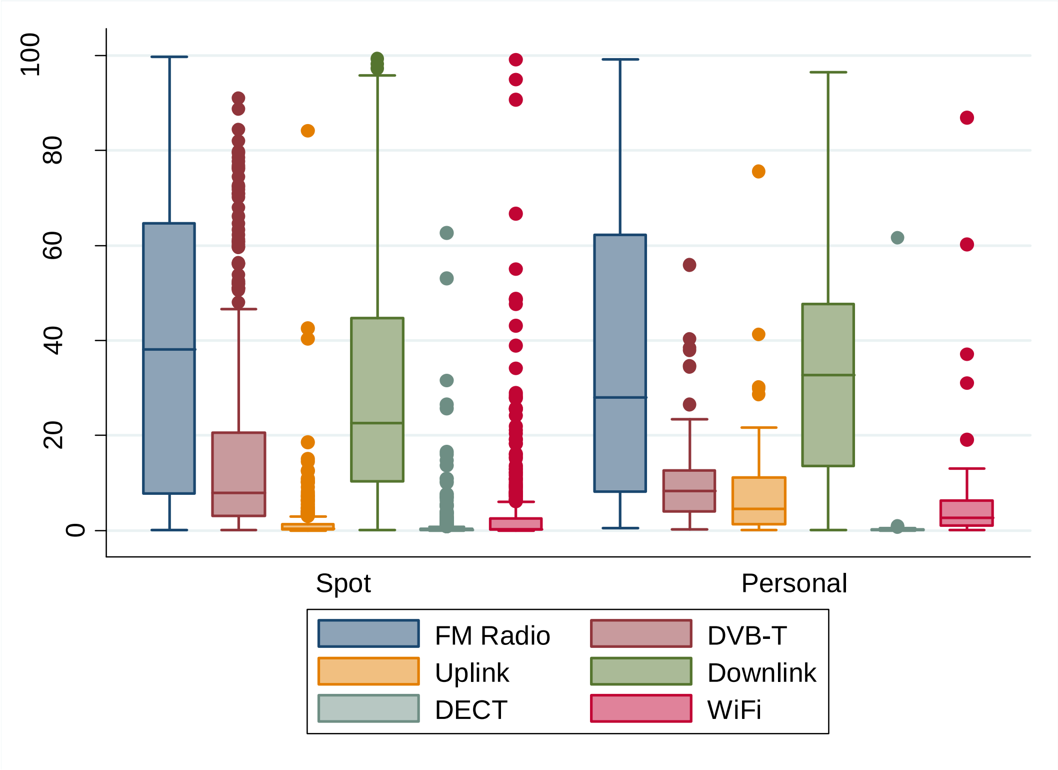

Figure 1: Contribution of different sources to total RF exposure

Comparison between personal measurements and approaches based on spot measurements

When considering mean and median values, exposure based on home and living room measurements were the assessment that yielded the most similar results to personal measurements respectively (home measurements were 1.09 and 1.49 times higher for mean and median respectively and living room measurements were 0.98 times lower), while own TWA-adjusted and own TWA-unadjusted were the most different, resulting in an overestimation of exposure (Table 2). However, lowest Spearman correlations were found between personal and living room measurements (0.51) and highest for median TWA-adjusted. Although correlations were moderate to strong, Bland-Altman plots showed that approaches based on spot measurements tended to overestimate exposure compared to personal measurements (Figure 2). In addition, the confidence interval (95%) of the mean difference between methods did not span zero. The plots revealed that there was a bias between personal measurements and all of the other approaches for absolute values that was proportional to power density.

Agreements between personal measurements and the different approaches based on spot measurements when classifying the participants into low, medium or high exposure groups are provided in Table 3 (categories of sources). For total RF exposure, median TWA-adjusted was the approach that agreed most closely with personal measurements while bedroom measurements showed the least agreement. Even though the agreement between personal total mean and home measurements was good (64.6%), Cohen´s kappa was moderate (0.39). For uplink exposure, there was no agreement between personal measurements and any of the approaches based on spot measurements. Personal downlink exposure was found to agree better, though moderately, with home measurements and with the median TWA-adjusted. For broadcast exposure, somewhat higher agreement, but still moderate, was found between personal measurement and all of the spot-based TWA approaches. Similar patterns were observed for the separate bands (Supplementary Table 4), spot home measurements agreed moderately well in most cases, and the agreement was better than that found between personal measurements and bedroom or living room-only spot measurements.

An assessment of possible systematic differences between the results obtained with each method based on spot measurements and personal measurements is provided in Supplementary Table 5. There were no systematic differences between personal measurements and any of the other approaches based on spot measurements used for any of the sources.

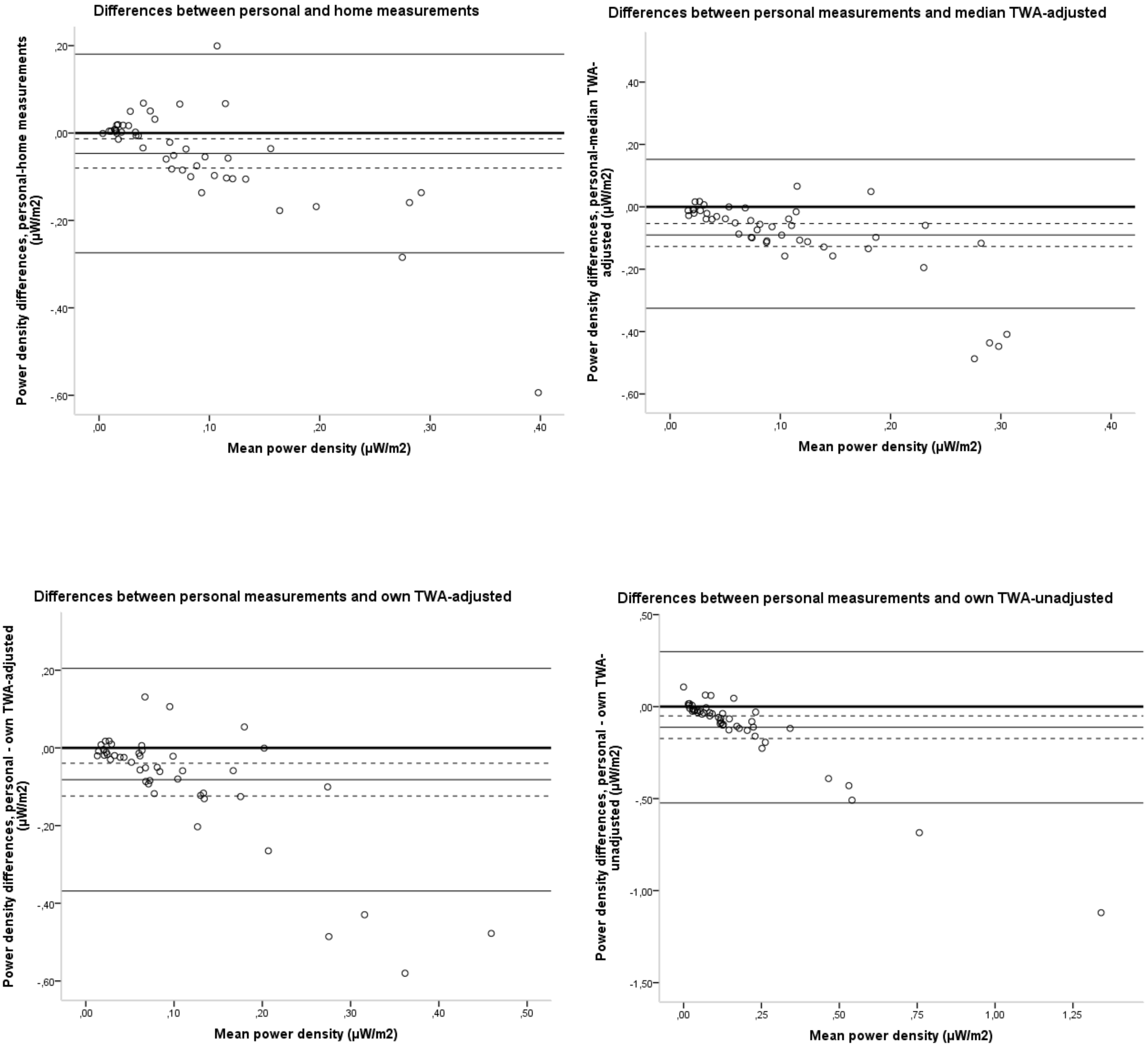

Figure 2: Bland-Altman plots of the mean RF levels. Vertical axes represent power density differences between personal measurement and each of the approaches based on spot measurements; horizontal axes represent mean power density of personal measurement and each of the approaches based on spot measurements; the solid bold line represents the difference zero between the two methods studied; the other solid lines represent the mean difference and mean difference ± 1.96 standard deviations; the dashed lines represent the confidence interval (95%) of the mean difference; The bias between the two methods is represented by the gap between the solid bold line and the mean difference line (solid non-bold line); two children were excluded since they were extreme outliers and made it difficult to plot the graphs

Table 3. Agreement between exposure classification obtained by personal measurements and other approaches based on spot measurements

	Home measurements[a]		Bedroom measurements[a]		Living room measurements[a]		Median TWA-adjusted[a]		Own TWA-adjusted[b]		Own TWA-unadjusted[b]	
	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]
DECT	68.75 (41.75)	0.46	41.67 (36.55)	0.08	56.25 (41.75)	0.25	60.42 (41.75)	0.32	59.57 (41.42)	0.31	59.57 (41.42)	0.31
WiFi[d]	52.08 (41.75)	0.18	39.58 (41.75)	-0.04	47.92 (41.75)	0.11	47.92 (41.75)	0.11	53.19 (41.42)	0.20	48.94 (41.42)	0.13
Broadcast	64.58 (41.75)	0.39	58.33 (41.75)	0.28	62.50 (41.75)	0.36	70.83 (41.75)	0.50	70.21 (41.42)	0.49	65.96 (41.42)	0.42
Downlink	68.75 (41.75)	0.46	62.50 (41.75)	0.36	58.33 (41.75)	0.28	66.67 (41.75)	0.43	61.70 (41.42)	0.35	61.70 (41.42)	0.35
Uplink	37.50 (41.75)	-0.07	52.08 (41.75)	0.18	41.67 (41.75)	-0.00	39.58 (41.75)	-0.04	48.94 (41.42)	0.13	40.43 (41.42)	-0.02
Total	64.58 (41.75)	0.39	56.25 (41.75)	0.25	60.42 (41.75)	0.32	68.75 (41.75)	0.46	63.83 (41.42)	0.38	63.83 (41.42)	0.38

[a]Cohen´s kappa was performed for 48 participants with complete information on personal and spot measurements; [b]Cohen´s kappa was calculated for 47 children that had complete questionnaire data; [c]Cohen´s kappa; [d]Only ISM 2.4 GHz was taken into account.

DISCUSSION

In this study we assessed RF exposure levels of a child population by several approaches. We conducted spot measurements in settings where children tend to spend most of their time and we compared results based on those measurements with those of personal measurements, which require greater efforts in terms of time and money. Median exposure for personal measurements was 52.13 µW/m^2 and ranged from 25.46 to 123.21 µW/m^2 for assessments based on spot measurements and from 29.73 to 200.10 µW/m^2 for spot measurements in the different settings. Based on both measurements, broadcast and mobile phone downlink were the sources that contributed most to total exposure. Highest though moderate kappa coefficient (0.49) was found between personal measurements and TWA based on spot measurements and on median number of hours reported for each setting (median TWA-adjusted).

A few studies have assessed exposure levels of children' or adolescents' [23,36–40], although, to our knowledge, ours is the first reporting spot measurements in the main places where children spend the most time in their daily lives, along with personal measurements in a subsample.

One of the strengths of the study has been including exposure assessment in schools. Few studies have assessed exposure levels in schools, despite the fact that children spend approximately a quarter of the day and around half the days of the year there. Our total mean (119.51 µW/m^2) is higher than that found by Roser et al., (2017) in Swiss schools (59.6 µW/m^2) [23] and by van Wel et al., (2017) in Dutch schools (70.5 µW/m^2) [41]. The latter used a similar methodology, though they conducted the measurements after school hours and therefore assumed that they would be underestimating exposure. Our median (81.10 µW/m^2) was similar, though somewhat lower, than that observed in Australian schools (0.179 V/m; 84.99 µW/m^2) [39]. In contrast, Verloock et al., (2014) and Vermeeren et al., (2013) found much higher levels (from 0.34 V/m [306.63 µW/m^2] in Belgium to 0.40 V/m [424.40 µW/m^2] in Greece), but it should be noted that they selected the schools for their proximity to potential sources like WiFi connection, DECT stations, broadcast transmitters and/or telecommunication base stations [38,40].

One of the limitations of this study was that even with a very sensitive device, readings from some sources were often (LTE 2600 UL; LTE 2600 DL) or almost always (WiMax 3.5; ISM 5.8) below the LOQ for both spot and personal measurements. In addition to concerns about LOQs, all the measuring devices may be affected by crosstalk, which is an out of band response and occurs when a signal in a specific frequency band is also erroneously registered by another band. This can occur either because some frequency bands are quite close to each other (GSM1800DL, DECT and UMTS UL) [42] or because harmonics of a frequency band have effects in other bands, specifically, harmonics of signals around 1800 MHz and sometimes 900 MHz cause crosstalk in 5 GHz WiFi [43]. Regarding the former, in this study, we took no specific measures, given that we considered this to be less of a problem with ExpoM than previous portable devices (ExpoM´s crosstalk is between -40 and -60 dB). Regarding the latter, we opted to consider only the 2.4 GHz signal for the wireless internet exposure estimate as the majority of wireless connection systems in our setting use this band.

Besides, we based on number of hours reported by parents in the questionnaires for calculating TWAs, which could induce bias in the exposure levels and classification. As other authors have indicated [44], participants may underestimate the amount of time spent at home. In fact, there was a mean difference of 2±4 hours between the actual time spent at home (as recorded in diaries completed during personal measurements) and that reported by parents in questionnaires. Those diaries were only available for the subsample with personal measurements (50 participants). In addition, even if the diaries are completed during personal measurements, and thus, recall bias could be minimized, they refer only to those three days with measurements, while schedule reported in the questionnaires refers to usual average timing.

Mean and median personal total exposure levels (169.19 and 52.13 µW/m^2), were within the range of previously reported values that ranged from 63.2 to 204 µW/m^2 (mean) and from 25.5 to 92 µW/m^2 (median) [23,45,46].

In line with other studies [40,47] RF exposure from outdoor environmental sources was higher outdoors than indoors. In this context, we should note that one school out of 26 in the study area, had its own radio antenna on the roof, which was in continuous operation, and this explains the very high FM Radio exposure levels found in a classroom of that school (36.94 mW/m^2). Interestingly, another school also had its own radio antenna, but in this case spot FM readings were within the 75th percentile (84.50 µW/m^2). For typical indoor environmental sources, such as WiFi and DECT, readings were higher indoors than outdoors, although still very low, in line with previous research [40]. It is important to state that in our study area, outdoor WiFi hotspots are not yet very common. WiFi exposure was higher in homes than in schools. DECT exposure was almost negligible and, as expected, highest in living rooms.

Regarding the contribution of sources, FM Radio was the one that contributed most, followed by downlink and DVB-T bands. This pattern was consistent in all settings and for both spot and personal measurements. Sources for personal use (uplink, WiFi and DECT) contributed in total less than 20% to the total exposure. In contrast, in a recent review, the authors observed that downlink and DECT were the sources that contributed most to RF exposure in homes [48] with small contributions from radio and TV-signals. While Beekhuizen et al., (2014) found that indoors TV and radio contributed 7% and 6% respectively [25], we found median contribution of as much as 55%. As in other studies [25], mobile phone use was not allowed during the spot measurements. Therefore, the contribution of the uplink in spot measurements is not representative of usual levels. In contrast, in previous personal measurement studies, contribution of uplink was predominant together with downlink and DECT [45,46] in adults and in the case of adolescents 67.2% of exposure was found to come from uplink [23]. According to this, we would expect the same to be observed in our study, but the difference in uplink contribution between the two approaches (spot and personal) was up to 6% (median and mean contributions to the personal measurements were 4.5% and 9.5%). Only 2 (4.1%) children that conducted valid personal measurements reported using a mobile phone regularly (at least once a week), but our participants were younger (8 years old) than those of Roser´s study (13-17 years old) [23]. Therefore, the uplink contribution in our personal measurements can be mainly attributed to the emissions of mobile phones of parents and other adults close to children. We consider that this underlines the relevance of personal use of phones to uplink exposure, which is greater than any exposure due to other people´s use of phones. An exception could be on public transport where other authors have found uplink to contribute most to total exposure [47,49]. Nevertheless, our sample of children did not tend to travel in public transport shared with other adults (trains/buses) where background uplink levels are high.

Given the lack of a standardized and widely accepted method to assess exposure to RF fields for epidemiological purposes, the methodology used varies greatly between studies. In recent years, geospatial models have been used as a surrogate for environmental exposure from mobile phone base stations or broadcast stations. Some authors have compared exposure levels obtained by such models with personal measurements at home [26] and spot measurements at home [21,25,27] in adult populations. However, they have focused only on downlink exposure.

Our study population is composed of children, and the amount of time they tend to spend in each type of setting, including home, may vary from patterns in adults. We assume that children usually have more structured daily habits. Therefore, it could be easier to identify the settings where they spend most of their time during the day; this would be useful in determining the most relevant settings for spot measurements, and in turn, in case of good agreement with personal measurements, would simplify the work related to exposure assessment. However, it should be noted that whether spot measurements simplify or not the assessment depends on the protocol. In our study, around 30 times more hours were invested for assessing exposure of 50 children by personal measurements compared to assessing by spot measurements. On the other hand, methodologies such as car-mounted measurements [50] or measurements using drones [51] would also considerably reduce time required, but these methodologies are not suitable for indoor environments, and therefore would not make possible to capture exposure from settings where children spend most of their time (homes and schools). In our study, total personal RF levels showed greatest similarity with home measurements in terms of average exposure. In contrast, highest Spearman correlation was found between personal and median TWA-adjusted (0.72) and lowest between personal and measurements in the living room (0.52). This suggest that even both personal and home measurements result in lower exposures than the TWAs, conducting measurements only in homes would lead to misclassification of personal exposure. Observing differences between personal total values and other exposure estimations by Bland-Altman plots revealed that approaches based on spot measurements overestimated exposure compared to personal measurements. In addition, difference increased with the increasing mean power density, this implying that differences between personal and the rest of the methods were power density-dependent. Nevertheless, given that in epidemiological studies the correct ranking of exposure is considered more important than precise values [52], we compared the different approaches employed by classifying individuals into exposure categories, as it has previously been used for children [35] and adults [21]. Frei et al., (2010) found a moderate Spearman correlation (0.42) between personal and spot measurements in bedrooms for total RF exposure [21]. In our study, agreement between exposure classification based on personal measurements and on each of the other approaches varied from 0.16 (spot measurements in bedrooms) to 0.49 (median TWA-adjusted). On the one hand, this would mean that median TWA-adjusted might be useful as a simple approach with which replace personal measurements. On the other hand, even if the bedroom is the place where children spend most time each day, conducting measurements only in bedrooms would lead to considerable misclassification when ranking study participants based on their exposure levels. Nonetheless, neither of the approaches led to a systematically different total exposure classification compared to the classification obtained by personal measurements. In general, median TWA-adjusted showed the best (but still moderate) agreement coefficients, with personal measurements. In contrast, when examining source by source, classification obtained by at home measurements showed the best agreement (coefficients of as high as 0.75 for DVB-T). No agreement was observed between classification based on personal measurement and that based on any of the other proxies in the case of uplink. It is important to underline, however, that when measurements were taken at home all RF emitting devices were required to be set as usual, but measurements were conducted without anyone in the rooms being measured, and hence, uplink levels at homes may not be representative of real exposure levels. Still, in both personal and spot measurements uplink made a minor contribution to total exposure.

All the methodologies used for RF exposure assessment have limitations. Exposure estimation based on spot measurements can be inadequate, as long as such measurements are only taken over a specific period of time, at a specific location and under specific circumstances regarding use of sources in the surroundings. Still, small temporal variations have been observed during daytime hours in earlier studies [53], while differences have been more pronounced between day- and night-hours with higher exposures during the day [23,38,48,53]. Few studies have reported differences on exposure levels between weekdays and weekends and no robust conclusions can be drawn yet. Some authors have not found differences between both periods [45,53] or have observed somewhat higher total RF exposures on weekends [23] or on Sundays [54] compared to the rest of the week, though exposure differences varies upon the frequency bands [54]. In contrast, Bolte and Eikelboom found 80% higher total RF exposures during worked-days than during non-worked days [46]. Conducting spot measurements in weekends is not as suitable as in weekdays, especially in indoor places like homes and schools. Given that one of the advantages of assessing exposure with spot measurements would be simplifying the field work, in this study we compared personal measurements that could include also weekend days with spot measurements that were only performed during weekdays. Thus, we did not take into account possible variation between weekdays and weekends. On the other hand, even if we assume that personal measurements are the ones that best capture the personal exposure in terms of time and spatial variations, they also present limitations, due to changes in behaviors of participants and the effect of body shielding on the readings [21,55]. Thus our results could also be interpreted as an underestimation of exposure by personal measurements compared to spot measurements, which was previously supported by other authors [56]. In any case, our results suggest that spot measurements could replace individualized and more comprehensive measurements, like the personal ones, in children in which the uplink contribution is still not relevant and if based on all relevant locations.

CONCLUSIONS

We assessed children´s RF exposure by several different approaches based on spot measurements and by personal measurements. Higher total RF levels were observed outdoors. Based on both approaches, broadcast and mobile phone downlink were the sources that contributed most, while mobile phone uplink and other indoor sources like WiFi or DECT made only minor contributions. Total personal average RF levels were most similar to measurements obtained in homes, but lowest Spearman correlation was found between personal measurements and homes (especially in living rooms). There was a proportional bias between personal and approaches based on spot measurements, the latter overestimating exposure compared to personal measurements. On the other hand, there were no systematic differences between personal measurements and other approaches when classifying children into exposure categories. Personal measurements for total RF agreed better, although only moderately well, with exposure estimates based on spot measurements in the main settings (homes, schools and parks) and taking into account overall median time spent in each setting considering times reported by all participants. Therefore, using TWA based on spot measurements could be a feasible proxy to rank personal RF exposure in children population, providing that they do not use the mobile phone frequently and that all relevant locations where children spend their time are captured.

ACKNOWLEDGMENTS

We would like to thank all INMA families for their active collaboration. We would also like to thank all the INMA-Gipuzkoa researchers, who helped when needed, especially Alain Noriega who was implicated in field work and Amaia Molinuevo who provided statistical advice. A full list of researchers can be found at:
http://www.proyectoinma.org/cohorts/gipuzkoa/en_membresgipuzkoa.html
MGa would like to thank the Department of Education, Language Policy and Culture of the Government of the Basque Country for a predoctoral research training grant (PRE-2016-2-0297)

Competing interests

The authors declare no conflict of interest.

Funding

This work has been funded by grants from the Spanish Carlos III Health Institute [FIS-FEDER PI13/02187 incl. FEDER funds; CP13/00054 incl. FEDER funds; MS13/00054], by donations of councils of the study region of Gipuzkoa and from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no 603794 – the GERONIMO project.

Ethical declaration

Prior to children's inclusion in the study, their legal guardians provided written informed consent. The research has been performed in accordance with the Spanish Law 14/2007 on Biomedical Research and the ethical principles of the Declaration of Helsinki. This work has been approved by the ethical committee of the Basque Country (CEIC-E).

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SUPPLEMENTARY MATERIAL

Supplementary Table 1

Frequency bands and measurement ranges of the ExpoM

	Band name	Frequency range	Lower limit (V/m)[a]	Upper limit (V/m)	Lower limit (μW/m^2)[a]	Upper limit (mW/m^2)
ExpoM	FM Radio	87.5 – 108 MHz	0.020	5	1.06	66.31
	DVB-T	470 – 790 MHz	0.005	5	0.07	66.31
	LTE800 downlink	791 – 821 MHz	0.005	5	0.07	66.31
	LTE800 uplink	832 – 862 MHz	0.005	5	0.07	66.31
	GSM900 uplink	880 – 915 MHz	0.005	5	0.07	66.31
	GSM900 downlink	925 – 960 MHz	0.005	5	0.07	66.31
	GSM1800 uplink	1710 – 1785 MHz	0.005	5	0.07	66.31
	GSM1800 downlink	1805 – 1880 MHz	0.005	5	0.07	66.31
	DECT	1880 – 1900 MHz	0.005	5	0.07	66.31
	UMTS uplink	1920 – 1980 MHz	0.003	5	0.02	66.31
	UMTS downlink	2110 – 2170 MHz	0.003	5	0.02	66.31
	ISM 2.4 GHz	2400 – 2485 MHz	0.005	5	0.07	66.31
	LTE2600 uplink	2500 – 2570 MHz	0.003	5	0.02	66.31
	LTE2600 downlink	2620 – 2690 MHz	0.003	5	0.02	66.31
	WiMax 3.5 GHz	3400 – 3600 MHz	0.003	3	0.02	23.87
	ISM 5.8 GHz / U-NII 1-2e	5150 – 5875 MHz	0.050	5	6.63	66.31

[a] The lower bounds of the measurement ranges correspond to the quantification limits; Sources: Fields at work. ExpoM-RF, radio frequency exposure meter. Available from: [http://www.fieldsatwork.ch/uploads/Downloads/Expom-RF_Fact_Sheet_2017.pdf (accessed 5.15.17)

Supplementary Table 2

Measurement procedure: spot and fixed longer-term measurements of radiofrequency (RF) electromagnetic fields

	N	Field	Frequency range	Duration (time interval)	Measurement site	Height	Device
INDOOR							
Homes & schools							
Bedroom/living room and two classrooms	104 & 26[a]	EF/MF	16 bands (87.5 MHz-5.8 GHz)[b]	2 minutes (4 s)	Center & all 4 corners	1.1, 1.5 & 1.7 m[c]	ExpoM
OUTDOOR							
Public parks/playgrounds & school playgrounds	78 & 26	EF/MF	16 bands (87.5 MHz-5.8 GHz)[b]	6 min (4 s)	Center	1.1, 1.5 & 1.7 m[c]	ExpoM
PERSONAL MEASUREMENTS	50	EF/MF	16 bands (87.5 MHz-5.8 GHz)[b]	72 hours (4 s)	Personal		ExpoM

EF: electric fields; MF: magnetic field; [a]2 classrooms were measured in each school, summing to 54 classrooms in total; [b]Frequency bands: 87.5 - 108 MHz; 470–790 MHz; 791 – 821 MHz; 832 – 862 MHz; 880 – 915 MHz; 925 –960 MHz; 1710 –1785 MHz; 1805 – 1880 MHz; 1880 – 1900 MHz; 1920 – 1980 MHz; 2110 – 2170 MHz; 2400–2485 MHz; 2500 – 2570 MHz; 2620 – 2690 MHz; 3400 – 3600 MHz; 5150 – 5875 MHz; [c]At 1.7, 1.1 and 1.5 m in the middle, and only at 1.5 m in the corners. In the corners at 1.4 meters from the corner

Supplementary Table 3. Characteristics of the subsamples with personal and with in-home measurements compared to the sample for which measurements were not taken

	Children with personal measurements (n=48)[a]	Children with in-home measurements & without personal measurements (n=56)[b]		Children with in-home measurements (n=104)	Children with no measurements[c](n=293)	
	n (%)	n (%)	p[d]	n (%)	n (%)	p[d]
Variables of the children						
Sex						
Female	24 (50.0)	23 (41.1)	0.362	47 (45.2)	153 (52.2)	0.218
Male	24 (50.0)	33 (58.9)		57 (54.8)	140 (47.8)	
Owns a mobile phone at 8 years of age[e]						
No	45 (95.7)	56 (100.0)	0.206	101 (98.1)	257 (93.5)	0.075
Yes	2 (4.3)	0 (0.0)		2 (1.9)	18 (6.5)	
Variables of the mother						
Age at child's birth						
<25	0 (0.0)	0 (0.0)	0.343	0 (0.0)	4 (1.4)	0.275
25-29	17 (35.4)	13 (23.2)		30 (28.9)	92 (31.4)	
30-34	26 (54.2)	34 (60.7)		60 (57.7)	143 (48.8)	
>35	5 (10.4)	9 (16.1)		14 (13.5)	54 (18.4)	
Country of birth						
Spain	48 (100.0)	55 (98.2)	1.000	103 (99.0)	284 (96.9)	0.465
Other	0 (0.0)	1 (1.8)		1 (1.0)	9 (3.1)	
Social class						
Non-manual	30 (62.5)	42 (75.0)	0.169	72 (69.2)	177 (60.4)	0.110
Manual	18 (37.5)	14 (25.0)		32 (30.8)	116 (39.6)	
Educational level[f]						
Primary	4 (8.3)	3 (5.3)	0.812	7 (6.7)	33 (11.3)	0.065
Secondary	15 (31.3)	16 (28.6)		31 (29.8)	111 (38.1)	
University	29 (60.4)	37 (66.1)		66 (63.5)	147 (50.5)	
Type of area[g]						
Rural/No urban	27 (56.3)	27 (48.2)	0.414	54 (51.9)	151 (51.5)	0.946
Urban	21 (43.7)	29 (51.8)		50 (48.1)	142 (48.5)	
Number of children						
1	4 (8.3)	6 (10.7)	0.749	10 (9.6)	26 (9.1)	0.874
>1	44 (91.7)	50 (89.3)		94 (90.4)	260 (90.9)	

Supplementary table 3 (continued)

	Children with personal measurements (n=48)[a]	Children with in-home measurements & without personal measurements (n=56)[b]		Children with in-home measurements (n=104)	Children with no measurements[c](n=293)	
	n (%)	n (%)	p[d]	n (%)	n (%)	p[d]
Indoor sources						
WiFi at home[h]						
No	6 (12.5)	3 (5.4)	0.296	9 (8.7)	18 (6.3)	0.422
Yes	42 (87.5)	53 (94.6)		95 (91.3)	267 (93.7)	
Cordless phone at home[h]						
No	13 (27.7)	10 (18.5)	0.275	23 (22.8)	82 (29.3)	0.209
Yes	34 (72.3)	48 (85.7)		78 (77.2)	198 (70.7)	
Outdoor sources						
Mobile Phone Base Station ≤300m						
None	43 (89.6)	45 (80.4)	0.194	88 (84.6)	255 (87.0)	0.537
≥1	5 (10.4)	11 (19.6)		16 (15.4)	38 (13.0)	
Mobile Phone Base Station ≤600m						
None	18 (37.5)	22 (39.3)	0.852	40 (38.5)	105 (35.8)	0.633
≥1	30 (62.5)	34 (60.7)		64 (61.5)	188 (64.2)	
DVB-T antenna ≤600 m						
None	40 (83.3)	48 (85.7)	0.737	88 (84.6)	248 (84.6)	0.995
≥1	8 (16.7)	8 (14.3)		16 (15.4)	45 (15.4)	

[a]With valid personal measurements; [b]The two subjects that conducted personal measurements but for which not valid readings were obtained, were also included; [c]Refers to families who continued participating in the INMA project during the 8 years old follow up, but whose homes were not measured, either because they were not selected for the subsample or because they refused to have measurements conducted in their homes; [d]Differences were tested by Chi square test. However, when expected counts were below 5, Fisher's exact test was used. Level of significance was 0.05; [e]Either a phone from the child or a phone shared with other family members; [f]Two mothers did not answer; [g]Population above 10,000 inhabitants was considered urban, between 2,000 and 10,000 semi-urban and below 2,000 rural; [h]Some mothers did not answer; Responsible companies provided us with information on the locations of broadcast (DVB-T and FM radio) antennas. The locations of mobile phone base stations were extracted from a software application of the Spanish Ministry of Energy, Tourism and Digital Agenda (https://geoportal.minetur.gob.es/VCTEL/vcne.do). Proximity to those sources was calculated using QGIS (version 2.18.11). Parents provided information that we considered relevant for the exposure and also information on sociodemographic characteristics via questionnaire.

Supplementary Table 4

Agreement between exposure classification obtained by personal measurements and other approaches based on spot measurements, source by source

Sources	Home measurements[a]		Bedroom measurements[a]		Living room measurements[a]		Median TWA-adjusted[a]		Own TWA-adjusted[b]		Own TWA-unadjusted[b]	
	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]	Agreement (expected)	K[c]
Broadcast												
FM Radio	66.67 (41.75)	0.43	62.50 (41.75)	0.36	68.75 (41.75)	0.46	70.83 (41.75)	0.50	70.21 (41.42)	0.49	74.47 (41.42)	0.56
DVB-T	85.42 (41.75)	0.75	81.25 (41.75)	0.68	64.58 (41.75)	0.39	79.17 (41.75)	0.64	82.98 (41.42)	0.71	74.47 (41.42)	0.56
Downlink												
LTE800	72.92 (41.75)	0.54	72.92 (41.75)	0.54	66.67 (41.32)	0.43	68.75 (41.75)	0.46	63.83 (41.42)	0.38	63.83 (41.42)	0.38
GSM900	66.67 (41.75)	0.43	66.67 (41.75)	0.43	64.58 (41.75)	0.39	66.67 (41.75)	0.43	65.96 (41.42)	0.42	61.70 (41.42)	0.35
GSM1800	62.50 (42.36)	0.35	70.83 (43.06)	0.49	56.25 (43.06)	0.23	50.00 (43.06)	0.12	53.19 (41.42)	0.20	48.94 (41.42)	0.13
UMTS	66.67 (41.75)	0.43	64.58 (41.75)	0.39	62.50 (41.75)	0.36	58.33 (41.75)	0.28	59.57 (41.42)	0.31	59.57 (41.42)	0.31
LTE2600	10.42 (10.42)	0.00	10.42 (10.42)	0.00	10.42 (10.42)	0.00	10.42 (10.42)	0.00	38.30 (41.42)	-0.05	46.81 (41.42)	0.09
Uplink												
LTE800	72.92 (41.75)	0.54	66.67 (41.75)	0.43	60.42 (41.75)	0.32	56.25 (41.54)	0.25	63.83 (41.42)	0.38	61.70 (41.42)	0.35
GSM900	56.25 (41.75)	0.25	35.42 (36.55)	-0.02	54.17 (41.75)	0.21	43.75 (42.36)	0.02	40.43 (41.42)	-0.02	42.55 (41.42)	0.02
GSM1800	41.67 (36.55)	0.08	37.50 (35.94)	0.02	37.50 (35.33)	0.03	54.17 (41.75)	0.21	44.68 (41.42)	0.06	55.32 (41.42)	0.24
UMTS	56.25 (41.75)	0.25	45.83 (41.54)	0.07	54.17 (41.75)	0.21	47.92 (41.75)	0.11	48.94 (41.42)	0.13	51.06 (41.42)	0.16
LTE2600	33.33 (35.94)	-0.04	10.42 (10.42)	0.00	33.33 (35.94)	-0.04	35.42 (36.55)	-0.02	42.55 (41.24)	0.02	30.04 (41.42)	-0.13
WiFi[d]												
ISM 2.4 GHz	52.08 (41.75)	0.18	39.58 (41.75)	-0.04	47.92 (41.75)	0.11	47.92 (41.75)	0.11	53.19 (41.42)	0.20	48.94 (41.42)	0.13

DVB-T: Digital Video Broadcasting-Terrestrial; LTE: Long Term Evolution; GSM: Global System for Mobile communications; UMTS: Universal Mobile Telecommunications System; [a]Cohen´s kappa was calculated for 48 children with complete information on personal and spot measurements; [b]Cohen´s kappa was calculated for 47 children with complete questionnaire data; [c]Cohen´s kappa; [d]Only ISM 2.4 GHz was taken into account.

Supplementary Table 5

Assessment of systematic differences between classification obtained by personal measurements and other approaches based on spot measurements

Sources	Group	Home measurements			p	Bedroom measurements			p	Living room measurements			p	Median-TWA--adjusted			p	Own TWA--adjusted			p	Own TWA--unadjusted			p
		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3	
Broadcast																									
	1	18	5	1		17	6	1		19	5	0		20	3	0		19	4	0		20	3	0	
FM Radio	2	5	12	2	1.000	6	11	2	1.000	4	12	3	0.726	4	12	3	1.000	4	12	3	1.000	3	13	3	1.0002
	3	1	2	2		1	2	2		1	2	2		0	3	2		0	3	2		0	3	2	
	1	22	2	0		21	3	0		17	7	0		22	2	0		21	2	0		20	3	0	
DVB-T	2	1	16	2	0.644	2	15	2	0.675	6	11	2	0.703	2	14	3	1.000	2	15	2	1.000	3	13	3	1.000
	3	1	1	3		1	1	3		1	1	3		0	3	2		0	2	3		0	3	2	
Downlink																									
	1	20	4	0		20	4	0		17	7	0		20	4	0		18	5	0		18	5	0	
LTE800	2	3	13	3	0.719	3	13	3	0.719	3	13	3	0.204	3	12	4	0.733	4	11	4	0.740	4	11	4	0.740
	3	1	2	2		1	2	2		2	1	2		1	3	1		1	3	1		1	3	1	
	1	19	5	0		18	6	0		19	5	0		18	6	0		17	6	0		16	7	0	
GSM900	2	5	11	3	1.000	6	11	2	1.000	4	11	4	0.740	6	11	2	1.000	6	11	2	1.000	7	10	2	1.000
	3	0	3	2		0	2	3		1	3	1		0	2	3		0	2	3		0	2	3	
	1	16	7	1		18	6	0		16	7	1		14	10	0		14	9	0		14	9	0	
GSM1800	2	8	10	1	0.706	6	11	2	1.000	8	8	3	0.751	10	6	3	1.000	9	8	2	1.000	9	7	3	1.000
	3	0	2	3		0	2	3		0	4	1		0	3	2		0	2	3		0	3	2	
	1	18	5	1		17	6	1		18	5	1		17	7	0		16	7	0		16	7	0	
UMTS	2	5	12	2	1.000	5	12	2	0.860	5	11	3	1.000	7	9	3	1.000	6	10	3	0.735	6	10	3	0.735
	3	1	2	2		2	1	2		1	3	1		0	3	2		1	2	2		1	2	2	

Supplementary Table 5 (continued)

Sources	Group	Home measurements			p	Bedroom measurements			p	Living room measurements			p	Median-TWA--adjusted			p	Own TWA--adjusted			p	Own TWA--unadjusted			p
		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3	
LTE2600	1																	11	9	3		13	8	2	
	2		a				a				a				a			10	7	2	0.929	7	9	3	0.926
	3																	2	3	0		3	2	0	
Uplink																									
LTE800	1	19	3	2		18	5	1		16	6	2		14	9	1		16	6	1		15	7	1	
	2	4	14	1	0.847	5	12	2	1.000	7	11	1	0.863	8	10	1	0.996	7	11	1	0.703	7	11	1	1.000
	3	1	2	2		1	2	2		1	2	2		1	1	3		0	2	3		1	1	3	
GSM900	1	17	5	2						15	8	1		14	9	1		12	9	2		13	9	1	
	2	6	10	3	0.904		a			6	10	3	0.515	8	7	4	0.911	9	7	3	1.000	8	7	4	0.911
	3	1	4	0						3	1	1		2	3	0		2	3	0		2	3	0	
GSM1800	1													16	7	1		13	8	2		15	6	2	
	2		a				a				a			7	9	3	1.000	8	8	3	1.000	7	10	2	0.894
	3													1	3	1		2	3	0		1	3	1	
UMTS	1	16	7	1	0.894	12	10	2		15	8	1		13	9	2		13	9	1		13	8	2	
	2	6	10	3		10	8	1	0.881	6	10	3	0.515	8	9	2	0.898	7	9	3	0.522	7	10	2	0.896
	3	2	2	1		1	2	2		3	1	1		3	1	1		3	1	1		3	1	1	
LTE2600	1																	10	11	2		10	12	1	
	2		a				a				a				a			8	9	2	0.370	9	6	4	0.258
	3																	4	0	1		4	1	0	

Supplementary Table 5 (continued)

Sources	Group	Home measurements			p	Bedroom measurements			p	Living room measurements			p	Median-TWA-adjusted			p	Own TWA-adjusted			p	Own TWA-unadjusted			p
		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3		1	2	3	
	1	18	5	1	0.700					15	8	1		17	6	1		15	7	1		15	7	1	
DECT	2	6	12	1			a			9	9	1	0.707	7	10	2	0.735	8	10	1	0.706	8	10	1	0.706
	3	0	2	3						0	2	3		0	3	2		0	2	3		0	2	3	
WiFi																									
	1	14	8	2		11	12	1		13	9	2		13	9	2		13	8	2		12	9	2	
ISM 2.4 GHz	2	7	10	2	0.896	11	6	2	0.871	8	9	2	0.898	8	9	2	0.898	6	11	2	0.399	7	10	2	0.405
	3	3	1	1		2	1	2		3	1	1		3	1	1		4	0	1		4	0	1	
	1	18	6	0		16	7	1		17	7	0		19	3	2		18	3	2		17	4	2	
Broadcast	2	5	11	3	0.731	7	10	2	1.000	5	11	3	0.343	5	13	1	0.321	5	13	1	0.321	6	12	1	0.334
	3	1	2	2		1	2	2		2	1	2		0	3	2		0	3	2		0	3	2	
	1	19	5	0		18	6	0		17	7	0		18	6	0		16	7	0		16	7	0	
Downlink	2	4	12	3	0.726	6	10	3	1.000	5	10	4	0.392	6	11	2	1.000	7	10	2	1.000	7	10	2	1.000
	3	1	2	2		0	3	2		2	2	1		0	2	3		0	2	3		0	2	3	
	1	12	11	1		15	8	1		13	10	1		12	10	2		13	9	1		11	11	1	
Uplink	2	9	6	4	0.601	5	10	4	0.232	8	7	4	0.596	9	7	3	0.929	7	9	3	0.522	9	7	3	0.532
	3	3	2	0		4	1	0		3	2	0		3	2	0		3	1	1		3	1	1	
	1	17	7	0		15	9	0		17	7	0		19	4	1		17	5	1		17	5	1	
Total	2	6	11	2	0.703	8	9	2	0.707	6	10	3	0.735	5	12	2	0.726	6	11	2	0.731	6	11	2	0.731
	3	1	1	3		1	1	3		1	2	2		0	3	2		0	3	2		0	3	2	

Group number 1 corresponds to children with exposure levels below the median; group number 2 to those with exposure levels from the median to the 90th percentile; and group number 3 to those with exposure levels equal or above the 90th percentile; DVB-T: Digital Video Broadcasting-Terrestrial; LTE: Long Term Evolution; GSM: Global System for Mobile communications; UMTS: Universal Mobile Telecommunications System; $p<0.05$ was considered significant; [a]children were classified into two groups, because only a few measurements were above the LOQ

CHARACTERIZATION OF RADIOFREQUENCY FIELDS WITH A BROADBAND DEVICE

Besides using a narrowband device (ExpoM-RF-3) explained in the previous manuscript, we used a NBM-550 Broadband Field Meter basic unit with an EF 0691 isotropic probe covering frequencies between 100 kHz and 6 GHz (Narda safety test solutions) for measuring broadband RF field strength in 105 parks. Specifications of the device are provided in Table 1.

Table 1

Frequency bands and measurement ranges of the EF-0691

	Frequency range	Lower limit (V/m)[a]	Upper limit (V/m)	Lower limit (µW/m^2)[a]	Upper limit (mW/m^2)
EF-0691	100 kHz-6 GHz	0.375	650	373.01	1120.69 W/m^2

[a]The lower bounds of the measurement ranges correspond to the quantification limits; Source: Narda safety test solutions. NBM E-Field-Probe EF 0691 datasheet [1]

The procedure varied as a function of the environment (indoor or outdoor) (Table 2) and is explained in detail in a previous publication (in the methodology of this thesis) [2].

All measurements were conducted from Monday to Friday (weekdays), with school measurements being performed during school-hours.

Most of the readings were below the LOQ of the device (0.375 V/m; 0.37 mW/m^2). Percentage of readings above the LOQ and maximum exposure levels across all readings are listed in Table 3. The highest reading found was 17.14 mW/m^2 in a living room.

Table 2
Measurement procedure: spot and fixed longer-term measurements of radiofrequency (RF) electromagnetic fields

	N	Field	Frequency range	Duration (time interval)	Measurement site	Height
INDOOR						
Homes & schools						
Bedroom/living room and two classrooms	104 & 26[a]	EF/MF	100 kHz-6 GHz	2 minutes (1 s)	Center	1.1 m
OUTDOOR						
Public parks/playgrounds & school playgrounds	105 & 26	EF/MF	100 kHz-6 GHz	Tracking[b]	Whole area	1.1 m
	105 & 26	EF/MF	100 kHz-6 GHz	20 minutes (1 s)	Max point[c]	1.1 m
	105 & 26	EF/MF	100 kHz-6 GHz	10 minutes (1 s)[d]	Center	1.1 m

EF: electric fields; MF: magnetic field; [a]2 classrooms were measured in each school, summing to 54 classrooms in total; [b]Tracking the whole area to determine maximum and average exposure levels; [c]At the location where maximum exposure was found during the tracking; [d]When the location with maximum exposure was in the center, a 20-minutes measurement was taken

Table 3
Percentage of readings above limit of quantification of the Narda device and maximum levels found among all readings

Setting	% of readings >LOQ	Maximum level (mW/m^2)
Homes		
Child´s room	2.9	12.67
Living room	6.3	17.14
School		
Classrooms	13.8	2.82[a]
Playground	41.0	0.78
Parks		
In the center	32.4	5.87
Tracking the whole park seeking the maximum value	98.1	212.28

LOQ: limit of quantification; [a]without including the extreme outlier with the radio antenna, including it the maximum was 56.9 mW/m^2.

When seeking maximum exposure locations (points) in parks, most of the values (98.1%) were above the LOQ. The mean±sd/median were 8.31±23.24/2.60 mW/m^2 and the highest single reading was 212.28 mW/m^2. Spearman's correlation coefficient between punctual maximum readings and 20-minute measurements in those points was 0.40.

Using this device which has a very high LOQ has been a limitation of the study. Probes from Narda have been used in other published studies [3–5] as well as by public organizations, such as the Spanish Ministry of Industry and this influenced our decision to include this type of device in our set of equipment. Besides, it allowed investigation of whole park areas to identify the highest levels in the area, and we noticed a moderate correlation between one-off peaks at specific points in given areas and average exposures for these points. Nevertheless, though this probe is useful to detect potential high values and to check that regulatory limits are not exceeded, most of the readings were well below the LOQ, meaning that it is not suitable for epidemiological purposes. Anyhow, we overcame this problem with the use of a narrowband exposimeter with a very low LOQ.

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Zein apartekoa! Zibilizaziorik aberatsena, bizi-itxaropen luzeenekoa, babestuena eta bere teknologia propioaren ezagutza handiena duena, beldurtienetarikoa bihurtzen ari da.

How extraordinary! The richest, longest-lived, best-protected, most resourceful civilization, with the highest degree of insight into its own technology, is on its way to becoming one of the most frightened
– Aaron Wildavsky

Irrati-maiztasuneko eremu elektromagnetikoekiko arriskuaren pertzepzioa INMA-Gipuzkoa kohortean

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Ondorengo izenburuarekin argitaratua: [Percepción del riesgo a campos electromagnéticos de radiofrecuencia en la cohorte INMA-Gipuzkoa]
Revista de Salud ambiental 2016; 16(2):118-126

LABURPENA

Biztanleriak ingurumen arriskuen inguruan duen pertzepzioa lehentasunezko gai bat da arrisku hauek kudeatzen dituzten erakunde eta administrazioentzat. Irrati-maiztasunen (IM) arriskuekiko pertzepzioari buruz ikerketa gutxi gauzatu dira, baina egindakoek biztanleriaren kezka maila altuak adierazten dituzte. Ikerketa honek INMA-Gipuzkoa proiektuko emakumeek IM-ekiko duten arriskuaren pertzepzioa aztertzen eta azaltzen du.

Pertzepzioari buruzko datuak galdetegi bidez jasoak izan ziren bi garai ezberdinetan. Alde batetik, haurdunaldian zehar 625 amek 16 ingurumen-arazoz osaturiko zerrenda batetik euren ustez euren bizitokian arriskutsuenak ziren 5 arazo hautatu zituzten. Bestetik, haurrek 8 urte betetakoan, 386 amek, 0tik 10erako eskalan, IM-ekiko esposizio-mailaren eta hauek osasunean duten arriskuaren inguruko euren pertzepzioa puntuatu zuten.

Haurdunaldian zehar amen % 31.8k hautatu zuten IM antenekiko gertutasuna 5 ingurumen-arazo nagusienetako bat gisa. Haurrek 8 urte betetakoan jaso zen galdetegian, amen % 98.0k (esposizioarekiko) eta % 90.3k (osasun-arazoekiko) pertzepzio-maila ertainak edo altuak (5 eta 10 artean) adierazi zituzten. Bi pertzepzio ezberdinen artean, esposizioa eta osasun-arriskuak, korrelazio moderatu bat (0.5) aurkitu zen. Ez da korrelaziorik aurkitzen IM-ekiko esposizioaren pertzepzioaren eta neurketa bidez etxebizitzetan erdietsitako benetako balioen artean. Biztanleriak arriskuen inguruan duen pertzepzioan eragiten duten aldagaiak ezagutzeak hauen kudeaketa egoki bat gauzatzen lagunduko du.

Hitz-gakoak: pertzepzioa; esposizioa; arriskua, irrati-maiztasunak, eremu elektromagnetikoak.

SARRERA

Ingurumen arriskuen eta hauek osasunean izan ditzaketen eraginen pertzepzioa lehentasunezko gaia da arrisku hauek kudeatzen dituzten erakunde eta administrazioentzat. Arriskuak sor ditzaketen eragileak naturalak zein teknologikoak izan daitezke. Gure inguruaren parte dira, eguneroko bizitzako gure ohituren, jokabideen eta gauzatzen ditugun ekintzen parte, laburki esanda gure bizitzeko moduaren parte. Hargatik, biztanleriak arrisku hauen ezagutza eta kudeaketa egoki bat eskatzen du, bide honi heltzea nahitaezko bihurtuz.

Berriki, Europar Batzordeak eskatutako ingurumen arriskuen pertzepzioaren inguruko txostenaren emaitzak argitaratu dira [1]. Emaitzek hiritar talde "adituek" eta "ez adituek" ingurumen arrisku garrantzitsuenen inguruan kualitatiboki bat-etortze maila altua dutela adierazten dute. Hala, bi taldeen arteko bateratasun bat ikus daiteke, hein batean 70. hamarkadan gauzatutako ikerketek aurkitutako bi talde hauek arriskuak zenbatesteko eta sailkatzerako orduan zeukaten desadostasuna zuzenduz. Desadostasun hauek gutxitze aldera arriskuen inguruko ezagutzak eta informazioak garrantzia berezia zutela pentsatu zen. Hala administrazio publikoek eta inplikatutako erakundeek ingurumen arazotzat zeuzkaten arriskuak hezkuntzaren eta informazioa eskaintzearen bidez konpontzea estrategia egokitzat hartu zen. 1987an, Slovic-ek [2] arriskuen pertzepzioa trebetasun azkar bat zela adierazi zuen, gertaeretatik soilik elikatzen ez dena, baizik eta emozioen eta esperientzien munduan barneratzen dena, inteligentzia emozionala kokatzen den lekuan hain zuzen ere; hala, beste helburu batzuen artean aurre egin beharreko arrisku garrantzitsuak modu azkar batean identifikatzea ahalbidetzen diguna.

Norbanakoaren arrisku pertzepzioan eragiten duten aldagaien artean, arrisku hauek murriztera edo kontrolatzera bideratzen direnetan garrantzitsuenak ondorengoak dira: norbanakoak arriskua kontrolatzen duenaren ustea; erakundeen kontrola (jendeak euren politiko, agintari edo arduradunetan konfiantza duenean); arriskua borondatezkoa edo norberak hartua izatea; arriskuarekiko ezaguntasuna/gertutasuna (arriskua zerbait ezaguna bezala sumatzen da, hala txikiagoa dela ulertuz) eta, azkenik, iturria naturala izatea. Bestalde, arrisku pertzepzioa handitzen duten aldagai nagusienak hauexek dira: kontrolaren ardura erakundeena izatea eta hauek sinesgarritasuna eta boterea galduak izatea; onuren eta kalteen banaketa orekatua ez dela sinestea; arriskuaren iturria antropogenikoa izatea; identifikatu daitezkeen eta honenbestez errua egotzi dakieken arduradunak egotea; hedadura eta inpaktu handia izatea, eta azkenik, etorkizuneko belaunaldiei eta biztanleria sentikorrari eragin ahal izatea. Aldagai hauez gain, biztanleriak bere ikuspuntua eta arriskuak ulertzeko modua identifikatuak sentitzen diren taldearen ideien arabera itxuraldatu ohi du. Ideia hau arriskuaren kognizio kulturalaren teoria gisa izendatua izan da [3].

Irrati-maiztasunekiko (IM) esposizioren eta osasun arriskuen pertzepzioa aztertzea helburu duten ikerketak oso urriak dira. Lortutako emaitzek ez dute informazio osoa azaltzen eta hutsune asko dituzte esposizioa zehazteko neurketa errealen erabilerari dagokionez. Berriki Portugaleko heldu gazteetan gauzatutako ikerketa batean, orokorrean, sumatzen den esposizioaren eta benetan neurtutakoaren artean dagoen erlazioa txikia zela ikusi zen. Bestalde, esposizioaren pertzepzioa arriskuaren pertzepzioarekin estuki lotua zegoela ondorioztatu zuten [4]. Egile hauek arriskua izan daitekeenaren zenbatestea heuristiko soilen erabileraren bidez egiten dela azpimarratzen dute. Hauek osagai ez kontziente altuko erabaki-hartze prozesu azkarrak dira, esposizioa zein handia, ohikoa edo iraunkorra denaren gisako ezaugarriak kontuan hartzen dituztenak. Antzerako emaitzak erdietsi ziren helduen lagin zabal batean Herbeheretan [5]. Lan honetan esposizio iturri posibleak modu objektiboan zehazteko eremu elektromagnetikoen (EEM) tarte ezberdinetarako benetako esposizioaren indikatzaileak (antenekiko eta tentsio altuko lineekiko gertutasuna) kontuan hartu ziren. Ikertzaile ezberdinek defendatzen duten ideia da esposizioak eta bere egitura kognitiboak arriskuaren pertzepzioan rol garrantzitsu bat jokatzen dutela [6,7].

Ikerketa honen helburua INMA-Gipuzkoa proiektuko kohorteko familiek irrati-maiztasuneko eremu elektromagnetikoen (IM-EEM) arriskuen inguruan duten pertzepzioa aztertzea da, eta baita pertzepzioak amen aldagai soziodemografikoekin eta etxebizitzetan neurtutako benetako esposizioekin duen erlazioa aztertzea ere.

METODOLOGIA

Ikertutako biztanleria

Ikertutako biztanleria INMA-Gipuzkoa kohorteko emakume haurdunek eta euren haurrek osatu zuten. Emakumeak 2006-2008 urteetan erreklutatu ziren haurdunaldiko lehen hiruhilekoan, Zumarragako ospitalean lehen ekografia egiterakoan, eta ezarritako onarpen baldintzen arabera [8]. Ikerketa esparrua Zumarragako ospitaleak barne hartzen dituen Goierriko eta Urola Garaiko eta Erdialdeko (Gipuzkoa) 25 herrik osatzen dute (90,000 biztanle inguru). Guztira 638 emakume sartu ziren ikerketan, eta informatuak izan zirenaren onarpen agiri bat sinatu zuten, ospitaleko etika batzordeak onartua. Horietatik 612 emakumek erditu zuten arrakastaz, eta 397 haurrek jarraitzen zuten ikerketa proiektuan 8 urte zituztenean. Ikerketa honetan 625 emakume (2006-2008 erreklutatuak) eta 386 haur (8 urte zituzteneko jarraipena 2014-2016an) sartu ziren, zeintzuk haurdunaldian galdetegi orokorra eta ingurumenekoa eta haurrek 8 urte zituztenean eremu elektromagnetikoen galdetegia bete zituzten.

Esposizioaren eta osasun-arazoen pertzepzioa

Ikerketa honetan arriskuaren pertzepzioa bitan banatu da, alde batetik proiektuko parte-hartzaileek esposizio mailen inguruan duten pertzepzioa (esposizioaren pertzepzioa), eta bestetik esposizio honek gizakiaren osasunean izan ditzakeen eraginen inguruko pertzepzioa (osasunerako arriskuaren pertzepzioa).

Haurdunaldian arriskuaren pertzepzioa galdetegi bidez jaso zen, non emakumeek 16 ingurumen-arazoz osaturiko zerrenda batetik (uraren, airearen zein elikagaien kutsadura, zarata, irrati-maiztasuneko antenekiko, tentsio altuko lineekiko zein industria desatseginekiko gertutasuna, inguru berdeen urritasuna, etab.) euren bizitokian ustez arriskutsuenak ziren 5 arazo hautatu behar zituzten.

Bestetik, haurrek 8 urte betetakoan, amek, 0tik 10erako eskalan, eguneroko bizitzan euren ustez IM-ekiko esposizioa zenbaterainokoa zen (telefonia mugikorreko antenak, irrati eta telebistako antenak, sakelako mugikorra, WiFi-a, etab.), (galdera honekin eta haurdunaldian egindakoarekin esposizioaren pertzepzioa aztertu zen), eta IMek zer punturarte eduki ditzaketen osasunean eragin kaltegarriak (osasunerako arriskuaren pertzepzioa) puntuatu zuten. Galdera honi erantzuteko IM-en iturri garrantzitsuenak irudikatzen zituen espektro elektromagnetikoaren eskema bat eman zitzaien.

Ikertutako aldagaiak

Haurdunaldiko lehen eta hirugarren hiruhilekoen artean, ekografietarako bisitekin batera, bi galdetegi bete ziren (orokorra eta ingurumenekoa), zeinetan amen eta euren inguruaren informazio ugari biltzen zen: bizi ziren ingurua, adina, jatorrizko herrialdea, heziketa maila, tabakismoa eta haurdunaldian zeharreko mugikorraren erabilera. Amaren lan motaren arabera "klase soziala" zeritzon aldagaia eraiki zen, Espainiako lanbideen sailkapen nazionalaren (CNO94)[9] arabera, non dauden 5 maila ezberdinak bi kategoria ezberdinetan multzokatu ziren: eskulangilea edo behe-mailakoa (IV eta V) eta ez-eskulangilea/aditua edo goi-mailakoa (I-III). Haurrek 8 urte betetzean IM-EEM neurketak gauzatu ziren 104 etxebizitzetan ExpoM-RF3 (Fields at work, Zurich, Suitza) esposimetro bidez, 87,5 MHz eta 6 GHz arteko maiztasunetan. Bi minutuko iraupeneko neurketak gauzatu ziren egongela nagusiko eta haurren geletako lau ertzetan eta erdiko puntuetan Gallastegi et al.-ek azaldutako metodologia jarraituz [10].

Analisi estatistikoa

Esposizioaren eta osasunerako arriskuaren pertzepzioak amen aldagai soziodemografikoen eta mugikorraren erabileraren arabera aztertu ziren, khi-karratu froga erabiliz eta medianaren balioaren arabera pertzepzioa bi taldetan sailkatuz. Esposizioaren pertzepzioaren eta etxebizitzetan neurketen bidez lortutako benetako IM-EEM balioen arteko erlazioa aztertzeko medianaren balioa (0,14 V/m)[6] hartu zen aintzat esposizio altuko eta baxuko guneak bereizteko. Esposizioaren pertzepzioaren eta osasunerako arriskuaren pertzepzioaren arteko korrelazioa Spearman-en korrelazio-froga bidez aztertu zen. Datuen analisirako IBM SPSS 21 programa erabili zen.

EMAITZAK

Haurdunaldian zehar amen % 31,8ak IM antenekiko gertutasuna hautatu zuen euren bizitokietako 5 ingurumen arazo garrantzitsuenetariko bat gisa, 5. postuan kokatuaz hain zuzen ere (1. irudia). Haurrek 8 urte zituztela amek 1etik 10erako eskalan esposizioaren pertzepzio gisa eta osasunerako arriskuaren pertzepzio gisa emandako batezbesteko balioak 8,16 (3-10 tartea; mediana 8) eta 7,13 (1-10 tartea; mediana 7) izan ziren hurrenez hurren. Familien % 71,4ak esposizioaren pertzepzio gisa emandako balioa ≥ 8 izan zen, eta % 69,2k osasunerako arriskuaren pertzepzio gisa emandako balioa ≥ 7.

1. Taulan antenekiko gertutasun gisa definitutako arriskuaren pertzepzioaren datuak aurkezten dira, aldagai soziodemografikoen eta amen eta haurren (8 urte zituztela) mugikorraren erabileraren arabera sailkatuak. Eskulangileak ez diren emakumeen %35,4ak sumatzen du IM antenekiko gertutasuna arrisku gisa, eskulangileak diren emakumeen kasuan aldiz %27,0k, ezberdintasun hau esanguratsua izanik (p = 0,027). Erditutako haurra lehenengoa izatea ala ez ere lotzen da IM antenak arrisku gisa hautatzearekin, haur bakarra dutenen %36.8k ikusten dute arrisku gisa, eta multiparoen kasuan balio hau %26,0koa da (p = 0,004).

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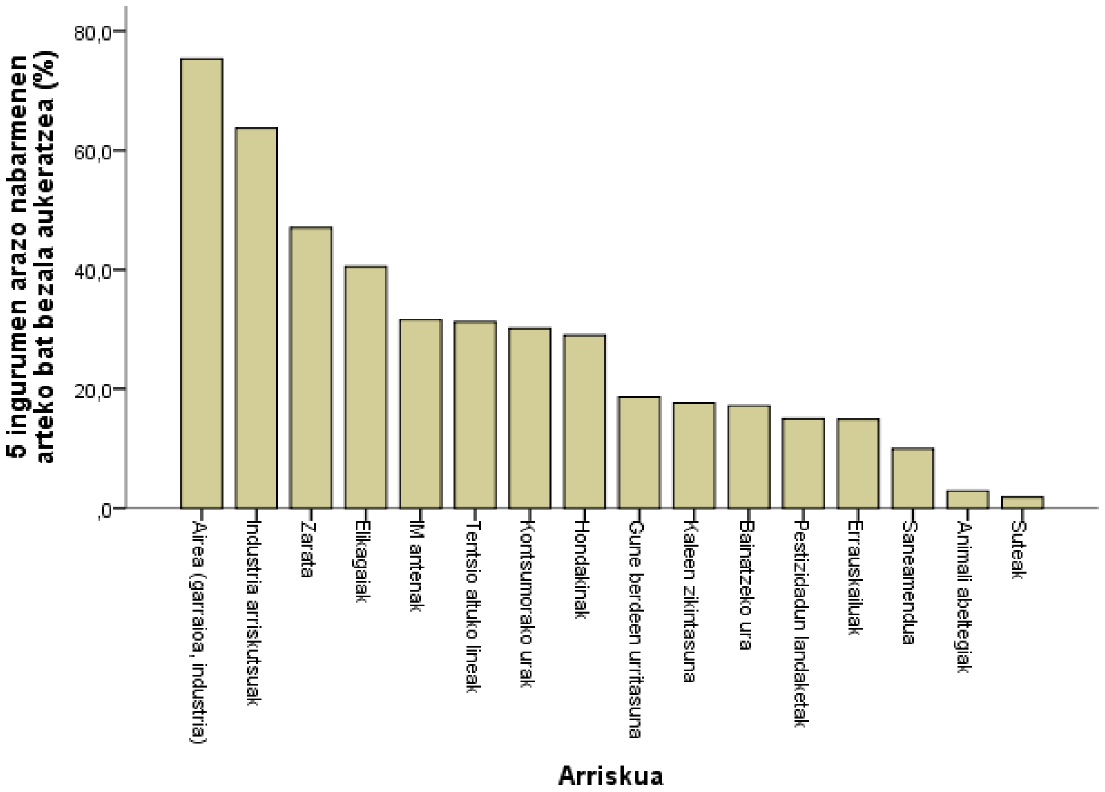
[6] Balio hau irrati maiztasunen esposizioaren inguruko artikulua egin baino lehenago kalkulatu zen, artikuluan adierazten diren zuzenketak egin gabe. Zuzenketekin logeletako eta egongeletako bataz besteko esposizioa 0.19 eta 0.27 V/m izan zen



1.irudia: Aukeran emandako 16 ingurumen arazoetatik 5 adierazgarrienen gisa aukeratutakoen ehunekoa (N=625).

Tabakismoaren aldagaiari dagokionez, ez-erretzaileen (inoiz ez dira izan ala erretzaile-ohiak dira) artean % 37,1ek hautatzen dituzte IM-ko antenak 5 arrisku nagusienetariko bat gisa, erretzaileen artean aldiz balio hau %21,0koa da ($p < 0.0001$). Ikasketa mailari dagokionez, ikasketa maila igo ahala pertzepzio maila altuagoa ikusten da, unibertsitate ikasketekin % 34,9, bigarren mailako ikasketekin % 30,3 eta lehen-mailakoekin % 25,0; dena den, ezberdintasun hau ez da esanguratsua. Orokorrean, emakume ez-eskulangileek, ikasketa unibertsitariodunek, 25 urte baino nagusiagoek, lehen haurra zutenek, ez-erretzaileek eta Espainiarrek arriskuaren pertzepzio handiago bat adierazten zuten. Emakumeen % 98,8k erabiltzen zuten mugikorra haurdunaldian zehar. Haurdunaldian zehar mugikorra erabiltzen ez zuten edo astean dei bat baino gutxiago egiten zuten 8 urteko haurren amek adierazi zuten IM antenekiko gertutasunaren arriskuaren pertzepzioa handiagoa izan zen, ezberdintasuna esanguratsua izanik ($p = 0,020$).

1. Taula. IMeko antenen arriskuaren pertzepzioa emakume haurdunetan[1] aldagai soziodemografikoen arabera (N = 625 ama/386 ume)

		N	***Lehentasunezko arrisku gisa kontsideratzen dute*** n (%)
Amaren aldagaiak haurdunaldian			
Klase soziala	Eskulangilea	263	**71 (27,0)**[c]
	Ez-eskulangilea	362	**128 (35,4)**
Ikasketa maila	Lehen hezkuntza	80	20 (25,0)
	Bigarren hezkuntza	228	69 (30,3)
	Unibertsitate ikasketak	315	110 (34,9)
Adina	<25	14	3 (21,4)
	25-29	189	58 (30,7)
	30-34	306	99 (32,4)
	>35	116	39 (33,6)
Jatorriko herrialdea	Atzerritarra	26	6 (23,1)
	Espainiarra	599	193 (32,2)
Eremu mota	Hiria	312	97 (31,1)
	Landa eremua/Herri ertaina	313	102 (32,6)
Mugikorraren erabilera haurdunaldian	Ez	7	1 (14,3)
	Bai	593	198 (33,4)
Umearen aldagaiak 8 urtetan			
Mugikorraren erabilera 8 urtetan[a]	Ez	358	113 (31,6)
	Bai	21	7 (33,3)
Telefono mugikorrarekin umeak egindako deien kopurua 8 urtetan[b]	Bat ere ez/< astean bat	335	**113 (33,7)**[d]
	Astean bat edo gehiago	39	**6 (15,4)**

[1] IM antenen esposizioa 5 ingurumen arrisku adierazgarrienen artean dagoela kontsideratzen duten emakumeak; [a]7 amak ez zuten erantzun; [b]12 amak ez zuten erantzun; Esanguratsua, [c]p=0,027; [d]p=0,020

Familia berberak haurdunaldi garaian eta haurrak 8 urte dituztenean aztertzerako garaian ikusten den arriskuaren eredua nahiko antzekoa da. Dena den, eskulangileak diren emakumeek osasunerako arriskuaren pertzepzio altuagoa dute (% 75,0) eskulangileak ez diren emakumeekin alderatu ezkero (% 65,7) nahiz eta esanguratsua ez izan (2. Taula). Bestalde, korrelazio bat ikus daiteke amek adierazitako esposizioaren pertzepzioaren eta osasunerako arriskuaren pertzepzioaren artean ($r = 0,5$; $p \leq 0,001$). Haurren mugikorraren erabilera (erabiltzen duten ala ez) ez zen lotu amek adierazitako esposizioaren eta osasunerako arriskuaren pertzepzioekin. Dena den, mugikorra erabiltzen ez zuten edo astean dei bat baino gutxiago egiten zuten 8 urteko haurren amek osasunerako arriskuaren pertzepzio altuagoa zuten, esanguratsua ez zen arren. (2. Taula).

Esposimetro bidez 104 etxebizitzetan erdietsitako IM mailak oso baxuak dira (batezbestekoa = 0,14 V/m; tartea 0,2-0,77 V/m) eta biztanleria orokorrarentzat eremu elektromagnetikoen esposiziorako oinarrizko mugak eta erreferentzia mailak ezartzen dituen 1999/519/EC Gomendioko [11] balioetatik oso behetik aurkitzen dira.

Ez zen aurkitu etxeetan neurtutako esposizio mailen eta amek adierazitako arriskuaren pertzepzioen (esposizioarena zein osasunerako arriskuarena) arteko loturarik (3. Taula). Dena den, esposizioaren eta osasunerako arriskuaren pertzepzioentzat medianaren puntuazio bera edo altuagoa adierazi zuten amen etxebizitzetan neurtutako esposizio mailak mediana (0,14 V/m) baino baxuagoak izan ziren.

2. Taula. Amen esposizioaren eta osasunerako arriskuen pertzepzioa umeek 8 urte zituztenean (N=386)

		N	**Esposizioaren pertzepzio altua (≥ 8)** **n (%)**	**Osasunerako arriskuaren pertzepzio altua (≥ 7)** **n (%)**
Amaren aldagaiak haurdunaldian				
Klase soziala	Eskulangilea	144	93 (67,9)	102 (75,0)
	Ez-eskulangilea	242	175 (73,5)	157 (65,7)
Ikasketa maila	Lehen hezkuntza	38	29 (85,3)	22 (64,7)
	Bigarren hezkuntza	138	91 (66,9)	99 (73,3)
	Unibertsitate ikasketak	208	148 (72,6)	138 (67,3)
Adina	<25	4	1 (33,3)	1 (33,3)
	25-29	119	77 (67,5)	82 (71,9)
	30-34	196	145 (75,5)	133 (68,9)
	≥35	67	45 (68,2)	43 (66,2)
Jatorriko herrialdea	Atzerritarra	9	5 (71,4)	5 (71,4)
	Espainiarra	377	263 (71,5)	254 (69,0)
Eremu mota	Hiria	183	136 (75,1)	127(70,6)
	Landa eremua/Herri ertaina	203	132 (68,0)	132 (67,7)
Mugikorraren erabilera haurdunaldian	Ez	4	4 (100,0)	2 (50,0)
	Bai	372	258 (71,5)	250 (69,3)

2. Taula (jarraipena)

		N	Esposizioaren pertzepzio altua (≥ 8) n (%)	Osasunerako arriskuaren pertzepzio altua (≥ 7) n (%)
Umeak 8 urte zitueneko aldagaiak				
Amaren ume kopurua	1	108	70 (70,1)	70 (70,7)
	≥1	288	198 (72,0)	189 (68,7)
Mugikorra edukitzea 8 urtetan[a]	Ez	358	256 (71,9)	244 (68,5)
	Bai	20	12 (63,2)	15(79,0)
Telefono mugikorrarekin umeak egindako deien kopurua 8 urtetan[a]	Bat ere ez/< astean bat	336	240 (72,1)	234 (70,3)
	Astean bat edo gehiago	37	24 (64,9)	21 (56,8)

[a] ama batzuk ez zuten erantzun

3. Taula. Etxebizitzetako Irrati-maiztasunen esposizioa –medianaren azpitik eta goitik- eta amen pertzepzioa

		<Mediana[1] n (%)	≥Mediana[1] n (%)	p
Esposizio mailaren pertzepzioa	<8 (N=19)	6 (31,6)	13 (68,4)	0,092
	≥8 (N=83)	44 (53,0)	39 (47,0)	
Irrati-maiztasunen esposizioarekin loturiko osasunerako arriskuaren pertzepzioa	<8 (N=45)	21 (46,7)	24 (53,3)	0,609
	≥8 (N=56)	29 (51,8)	27 (48,2)	

[1] Medianaren balioa 0.14 V/m da; Ez ziren asosiazio esanguratsuak aurkitu

EZTABAIDA

Haurdunaldian zehar betetako galdetegian amen % 31,8ak "IM antenekiko (mugikor, irrati, etabar) gertutasuna" hautatu zuen ingurumenarekin loturiko 5 osasun arazo garrantzitsuenetariko bat gisa, 5. postuan kokatuz hain zuzen ere. EEM-ei buruzko azken eurobarometroan, 15 ingurumen arazo agertzen ziren osasunean eragin dezaketen kaltea puntuatzeko eta telefonia mugikorreko antenak eta mugikorrak 12. eta 13. postuetan gelditu ziren hurrenez hurren Europan, eta 8. eta 13. postuetan Espainian, bi kasuetan produktu kimikoen, elikagaien, uraren eta zarataren atzetik, beste batzuen artean [12]. Nahiz eta gure galdetegiaren eta eurobarometroarenaren artean galdera azaltzerako orduan eta arriskuaren pertzepzioa zenbatesterako orduan ezberdintasunak egon, lortutako emaitzek INMA-Gipuzkoa kohortea Europar eta Espainiar biztanleriarekin alderatuz IM-en esposizioarekiko bereziki sentsibilizatua dagoela adierazten dute. Gure galdetegian eremu elektromagnetikoen beste iturri batzuk, zehazki tentsio altuko lineak, IM antenak baino postu bat atzerago hautatuak izan ziren. Beste ikerketa batzuetan alderantzizko hurrenkera ikusi dute [12,13].

8 urtetara esposizioaren pertzepzioa osasunerako arriskuarena baino altuagoa da, baina biak dira altuak nolanahi ere, 8,16 eta 7,13 puntuko batezbestekoekin hurrenez hurren. Galdetegia betetakoen % 98.0k (esposizioarentzat) eta % 90,3k (arriskuarentzat) maila moderatuak edo altuak (≥ 5) sumatzen dituzte hurrenez hurren. Eurobarometroaren emaitzek europarren % 70ak eta espainiarren % 75ak telefonia mugikorraren antenek neurri baxuagoan ala altuagoan baina osasunean eragiten dutela uste dutela adierazten dute [12]. 6 europar herrialdetan egindako ikerketa batean galdetutakoen % 55ak IMekiko esposizioa altua edo oso altua (puntuazioa 5etik ≥ 4) sumatzen zuela ikusi zuten [7]. Portugalen burututako beste ikerketa batean, 838 pertsonek 5eko eskalan 3,53ko eta 3,74ko batezbesteko balioak eman zituzten telefonia mugikorreko antenen esposizioarentzat eta osasunerako arriskuarentzat, eta 3,01eko eta 3,01eko batezbesteko balioak mugikorren erabileraren esposizioarentzat eta osasunerako arriskuarentzat [14]. INMA-Gipuzkoa kohortean lortutako emaitzek kezka maila altua adierazten dute lehen ikerketekin alderatuz, baina Portugalen erdietsitakoaren antzekoa. Dena den, erabilitako eskalen arteko ezberdintasunek emaitzen alderagarritasuna zailtzen dute. Gure ikerketan, esposizioaren pertzepzioa arriskuaren pertzepzioarekin moderatuki korrelazionatzen da modu esanguratsuan (rho = 0,5; $p \leq 0,001$). Korrelazio hau Portugaleko ikerketan erdietsi zutenaren antzekoa da. Beraiek ere korrelazio moderatu bat aurkitu zuten esposizioaren pertzepzioaren eta iturri ezberdinen araberako osasunerako arriskuaren artean; antenak (r = 0,45), mugikorrak (r = 0,55) eta hari gabeko sareak (r = 0,45) ($p \leq 0,001$) [14],

honek esposizioaren pertzepzioak osasunerako arriskuaren pertzepzioan eragiten duela adierazten duelarik.

Haurdunaldian IM antenekiko gertutasun gisa adierazitako arriskuaren pertzepzioa handiagoa izatea klase sozial altuago batekin, haur bakarra izatearekin, ez-erretzaile izatearekin eta haurrak 8 urte dituela egindako mugikorreko dei kopuruarekin erlazionatzen da. Dena den, 8 urtetara osasunerako arriskuaren pertzepzioa amaren klase sozial baxuago batekin lotzen da, nahiz eta esanguratsua ez izan. Beste egile batzuk heziketa maila edo ikasketen urte kopuru altuagoa eta arriskuaren pertzepzioa uztartuta daudela ikusi zuten [15]. Kim et al.-ek (2014), beste egile batzuen gisan, IM-en esposizioaren inguruko jakintza handiagoa zutela adierazten zuten pertsonek kezka maila altuagoak aurkezten zituztela ikusi zuten [6,16]. Era berean, Freudenstein et al.-ek (2015) ere adina, generoa eta estatus soziala arriskuaren pertzepzioarekin lotu zituzten, baina azaldutako bariantzak baxuak ziren [14]. Gainera, klase soziala parte-hartzaileek eurek adierazi zuten, honek sailkapen okerrak gauzatzea sor dezakeelarik.

Beste ikerketa batzuetan gertatu gisan [5,14] ez genuen loturarik aurkitu pertzepzioaren eta etxebizitzetan neurtutako IM balioen artean. Dena den, gure kasuan, euren etxebizitzetan mediana baino esposizio maila baxuagoak dituztenek arriskuaren pertzepzio handiago bat adierazten dute.

Ikerketa honek duen mugetako bat pertzepzioa zenbatesterako orduan zuzendutako galdetak modu ireki eta orokor batean aurkeztu izana da. Bestalde, 8 urtetara galderak etxebizitzetako neurketekin batera gauzatu ziren, eta honek erantzunetan eragina izan dezake. Beste muga bat, gure emaitzak biztanleria orokorrera ezin direla estrapolatu da, gure kasuan parte-hartzaile guztiak emakume gazte haurdunak izan baitira. Zentzu honetan, egile batzuk emakumeetan kezka maila altuagoak aurkitu zituzten [15,17].

IM-en esposizioari eta osasun efektuei buruzko ikerketekin batera, beharrezkoa da biztanleriak arriskua nola sumatzen duen jakitea honen kudeaketa egoki bat gauzatu ahal izateko. Hainbat saiakera egin izan dira esposizio mailak murriztu [18] eta agintariek hartutako neurriak jakinarazteko [19], baina orain arte uste ez zen bezala [20], badirudi biztanleriari informazioa eskaintzea ez dagoela kezka mailen jaitsiera batekin lotuta [19], eta are gehiago kezka maila handitu ere egin dezakeela [21]. Honen arrazoia biztanleriak agintariek neurriak hartzea arriskua handiagoa den seinale bezala ulertzen dutela izan daiteke. Nahiz eta norbanakoen eguneroko hautuzko ekintzen ondorioz jasotako esposizioa gutxiestera eta telefonia mugikorraren antenen esposizioa balioestera jotzen dugun [4], oroitu behar da helduen esposizio maila altuenak norbanakoak gailu ezberdinak erabiltzetik datorrela, telefono mugikorrak kasu [22].

Jakina da arriskuaren kontrola norberak izatea eta hau hautazkoa izatea pertzepzioaren maila jaisteko joera duten bi aldagai direla [2]. Azkenik, arriskuaren pertzepzio mailak jaisterako orduan biztanleriak agintariengan konfiantza izatea oso garrantzitsua dela uste da [13,23]. Hori dela eta, ezinbestekoa da arriskuen kudeaketa egoki bat gauzatzea. Agintariek eta erakundeek biztanleria eta inplikatutako aldeak parte-hartzaile bihurtu behar dituzte, hala arriskuak ulertzea bultzatuz eta elkarrizketa eta erabaki-hartzeak erraztuz.

Ondorio gisa, ikerketa honek emakume gazteen lagin bat hartuz IM-ekiko arriskuaren pertzepzioaren ezagutza hobe bat erdiesten laguntzen du. Nahiz eta etxebizitzetan neurtutako esposizio mailak baxuak izan, parte-hartzaileek esposizioaren eta honek osasunean eragin dezakeen arriskuaren pertzepzio altuak dituzte. Aldagai deskriptiboekin ez da erlazio argirik ikusten, baina bai ikusten dela amaren arriskuaren pertzepzioak haurraren mugikorraren erabilera baldintzatzen duela.

EEM-ekiko arriskuaren pertzepzioa ziurrenik esposizio beraren ezaugarrietatik eta gizarteari loturiko aldagai sozial, kultural eta ekonomikoetatik eraikitzen da. Aldagai hauek ezagutzea lagungarri izan daiteke arriskuaren pertzepzioa modu egoki batean kudeatzerako orduan.

Eskerrak

INMA-Gipuzkoa proiektuaren parte diren familiak eskertu nahi ditugu ikerketan kolaboratzeagatik, ezinbestekoak baitira proiektuaren helburuak betetzeko.

Mara Gallastegik Eusko Jaurlaritzako Hezkuntza, Hizkuntza Politika eta Kultura saila eskertzen du jasotako doktorego-aurreko laguntzarengatik (PRE-2015_2_0263).

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It is our environment or ourselves that have changed? Would people like us have had this sort of concern in the past? Today there are risks from numerous small dams far exceeding those from nuclear reactors. Why is the one feared and not the other? It is just that we are used to the old or are some of us looking differently at essentially the same sort of experience?- Aaron Wildavsky

Exposure and health risks perception of extremely low frequency and radiofrequency fields and the effect of providing information

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In preparation for submission

ABSTRACT

Given that regardless of actual exposure levels, high-risk perceptions of electromagnetic fields of non-ionizing radiation (EMF-NIR) may cause health effects, it is important to understand the mechanisms behind perceptions in the general population. The aims of this study were to assess perceptions of both exposure and health-risk among mothers of the INMA (Environment and childhood)-Gipuzkoa child cohort; to evaluate whether providing information has any effect on perceptions; and to explore possible determinants that explain such perceptions. Overall, 387 mothers completed a questionnaire composed of four questions on perceived exposure and perceived health-risk of exposure to extremely low frequency (ELF) and radiofrequency (RF) fields answered on a Likert-type scale from 0 to 10. Later, measurements of ELF and RF fields were conducted in the houses of a subsample of 104 participants. All measured levels were far below the levels permitted by Spanish regulations. This was explained in the individual reports sent to the families. After reading the results, mothers completed the aforementioned questionnaire a second time, plus two additional questions regarding whether they had received information about exposure or effects of EMFs from public bodies before this project and whether they thought that public bodies should provide the aforementioned information.

Wilcoxon signed-rank test was conducted to assess the effect of receiving information. The association between perceived and measured levels as categorical variables was assessed with a chi-square test. Multiple linear regressions were conducted for each of the questions related to perceived exposure and health-risk perceptions.

Both exposure and health risk were perceived to be very high for both ELF and RF fields, with mean and medians around 7-8 on a 10-point scale. Providing information did not alter health-risk perceptions, but mean perceived RF exposure decreased significantly (by 0.7 points). Reporting higher perception levels was not associated with higher levels of exposure measured at home. Variables that were repeatedly associated with higher perceptions included manual social class, living in an urban area, having the feeling of living in a good neighborhood, often being bothered by air pollution when opening a window, being younger and having fewer devices at home. Most of the participants claimed to have received no or insufficient information from public bodies and considered very it very important that they should.

Keywords: Risk perception; exposure; extremely low frequency; radiofrequencies; electromagnetic fields; risk communication

Highlights:

- Exposure and health risk perceptions of electromagnetic fields (EMF) were assessed
- Mothers of a child cohort completed a survey before and after receiving information
- Levels of exposure and health-risk perception were very high
- Information did not alter health-risk perceptions but perceived exposure decreased
- Manual social class, younger age and having fewer devices increased perception

INTRODUCTION

The relevance of environmental hazards in public health has been increasing over recent decades. Simultaneously, concern about the health effects of pollutants has grown among the general population [1]. From a psychobiological point of view, risk perception allows us to quickly identify important threats that we must take action to counter [2]. It has been shown that perception and acceptance of risk are influenced by sociocultural factors [2,3], among others. Specifically, risk perception seems to be lower in the presence of the following factors, and higher under opposite conditions: familiarity with the risk; personal control of the risk and the fact that the risk is taken voluntarily; low potential effects; trust in public bodies; a balance between risks and benefits; natural origin of the risk; and a lack of risk to future generations and vulnerable groups [2,4]. Level of knowledge regarding potentially risky activities or elements has also been reported to be relevant for risk perception, but the directionality (whether perceived risk decreases or increases) is not clear [5,6].

Even though electromagnetic fields of non-ionizing radiation (EMF-NIR) have always been present in nature, rapid development of diverse technologies using these fields has led to an increase in exposure levels [7], at the same time that the exposure has become more evident (for example, with visible mobile phone antennas on roofs and more visibility of high voltage power lines due to the extension of urban areas). Despite numerous studies investigating EMF-NIR, there continues to be a lack of agreement between scientists regarding potential health effects of this type of radiation [8], and hence, it is essential to continue conducting studies assessing those effects. On the other hand, given that high risk perception could in itself be damaging to health by triggering non-specific symptoms which individuals attribute to a perceived high exposure [9], it is also necessary to explore perceptions of the population and to delve into underlying factors. Nevertheless, up to now, few studies have assessed risk perception related to EMF-NIR. It is important that public agencies that are responsible for regulating health policies understand the mechanisms behind perceptions in the general population.

The aims of this study were to assess exposure and health-risk perceptions among mothers of the INMA-Gipuzkoa (*Infancia y Medio Ambiente*-Environment and childhood) child cohort (www.proyectoinma.com); to evaluate whether providing information has any effect on perceptions; and to explore possible determinants that explain such perceptions.

METHODS

Study population

This study was embedded in the INMA-Gipuzkoa birth cohort, Gipuzkoa being a province of the Basque Country, and is part of the Spanish INMA cohort study (Guxens et al., 2012). The recruitment of mother-child pairs took place during the first antenatal visit (10-13 weeks of gestation) to the physician in the public referral hospital (Zumarraga hospital) between April 2006 and January 2008.

In total, 638 mother-child pairs were enrolled in the cohort study. Over the period 2014–2016, when the children reached 8 years of age, cohort members were contacted; at that time, 397 children (62.2%) took part in the follow-up. This study was conducted when the children were 8-years old and mothers of 387 of the children (out of the total of 397 children) participated in this study. Figure 1 illustrates a flowchart of the main phases of the project and the selection of participants.

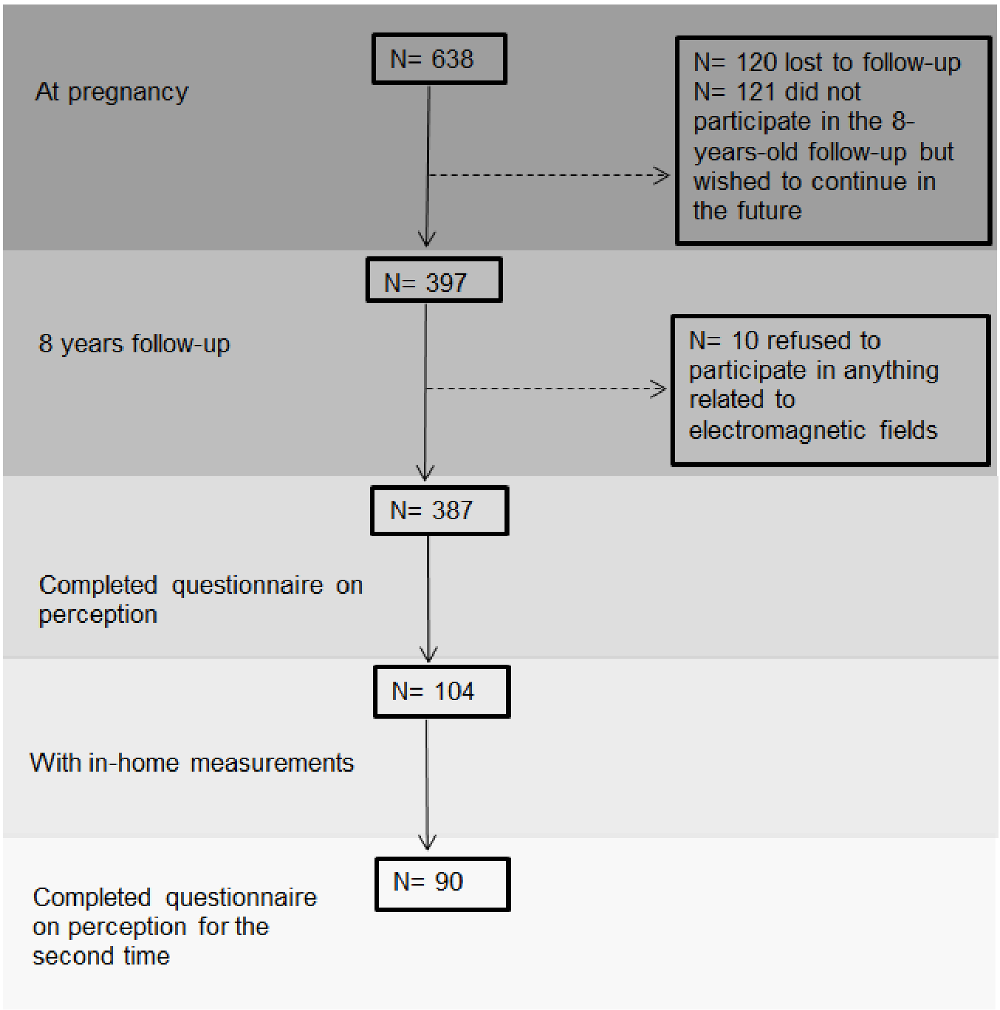

Figure 1: Flow chart of the number of participants

Study procedure

Mothers of children from the cohort (n=387) completed a questionnaire regarding risk perception (hereinafter questionnaire 1). In this study risk perception considers both the perception that the participants have of exposure levels (hereinafter “exposure perception”) and their perception of the effects of such exposure on human health (hereinafter “health-risk perception”). This questionnaire was composed of four questions: two regarding extremely low frequency (ELF) fields and two regarding radiofrequency (RF) fields, in each case one question assessing exposure and the other the perceived health risk of such exposure. The participants were asked to respond on a Likert-type scale (from 0 to 10; with 0 meaning no exposure or risk of health-effects and 10 meaning very high exposure or severe risk of health-effects). Translations of the questions used are presented in Table 1. To provide context for answering the questions, an informative figure was provided to the participants, showing the most common sources of each type of field.

We conducted measurements of both ELF and RF fields in the houses of a subsample of 104 participants. The measurement procedure is described in a previous publication [10]. In brief, measurements were conducted in the child´s room and living room. For ELF fields, in this study, we used 24-hour measurements, taken with an EHP-50D probe from Narda Safety Test Solutions (Germany) from 6 Hz to 500 Hz and with a measurement-interval of 30 seconds. The probe was placed in the living room during the day and in child’s room during the night. In the case of RF fields, spot measurements were conducted in both rooms in the center (at 1.1, 1.5 and 1.7 meters above the floor) and at the four corners (at 1.5 meters above floor and at 1.4 meters from the corner). For these, the device used was an ExpoM-RF 3, exploring a frequency band between 87.5 MHz and 6 GHz, with a measurement-interval of 4 seconds.

Participants were provided with individualized reports of the in-home measurements results. Along with these data, we sent them a new questionnaire (hereinafter questionnaire 2), which they were asked to complete once they had read the report. This questionnaire included the same four questions as the first questionnaire and two additional questions concerning the role of public health bodies in risk communication; specifically, we asked them whether they had received information about EMF exposure or its effects of from public bodies before this project; and whether they thought that public bodies should provide such information (Table 1).

Table 1

Statements of questions

Questionnaire 1	1. To what extent do you think we are exposed to extremely low frequency (ELF) electromagnetic fields in our daily lives?	Questionnaire 2
	2. To what extent do you think we are exposed to radiofrequency (RF) electromagnetic fields in our daily lives?	
	3. To what extent do you think that ELF electromagnetic fields may have negative health effects?	
	4. To what extent do you think that RF electromagnetic fields may have negative health effects?	
	5. Before this project, had you received information on the levels of exposure and/or effects that electromagnetic fields may have on health from any public body?	
	6. Do you think that public bodies should provide information on exposure levels and on health effects of electromagnetic fields?	

Data collection

Possible explanatory variables considered in this study are described in Supplementary Table 1. In brief, a questionnaire completed by the mother was used to gather data on maternal sociodemographic characteristics, and information regarding indoor sources of EMF exposure in the home in general and possible personal sources of EMF exposure for the children in particular. Proximity to outdoor exposure sources was provided by companies or institutions responsible for the emitters. Maternal mental health and intelligence were assessed with validated tests (General Health Questionnaire, GHQ-12 [11] and Symptom Checklist-90 Revised, SCL-R-90 [12], and Wechsler Adult Intelligence Scale-III [13] respectively). Schools' principals' provided information on the type of internet connection.

Data handling and statistical analysis

Representability of the subsample with in-home measurements was assessed in terms of relevant characteristics by Chi square test. Differences between responses given before and after reading the results regarding exposure levels were assessed with Wilcoxon signed-rank test. We also compared means and 95% confidence intervals (CIs) of perception before and after receiving information regarding exposure levels measured at home.

Spearman's correlations were performed between responses given to the same questions in the first and second questionnaire; between responses given to questions concerning exposure perception of ELF and of RF; between responses given to questions concerning perception of ELF and of RF health-risk; and between responses given for exposure-perception of a source and health-risk perception of the same source.

The association between perception and measured levels (both as categorical variables) was assessed using chi-square test.

Multiple linear regressions were conducted for each of the questions related to exposure perception and health-risk perception. The criterion for statistical significance was $p<0.05$. All independent variables with a $p<0.20$ according to the Mann-Whitney U test for dichotomous independent variables and Kruskal-Wallis test for polytomous independent variables were included in any of the models. Numerical variables were also included in the models if the p value was less than 0.2 in the linear regression models. Data on variables related to mental health and intelligence were only available for a subsample. The influence of these variables was assessed by sensitivity analysis, by adjusting the models with these variables when the p value was less than 0.2 in the linear regressions. Additionally, we assessed whether mothers were adequately aware of the presence or absence of WiFi in their children's schools, by comparing what mothers reported with data provided by school principals.

Data were analyzed with QGIS (version 2.18.11) and Stata (version 14; StataCorp, College Station, TX, USA).

RESULTS

Most of the mothers that completed the first questionnaire were between 30 and 34 years old when they gave birth to the children in the INMA cohort; were Spanish; were non-smokers during pregnancy; were categorized as from a non-manual social class; had university-level qualifications; had more than one child; used a mobile phone regularly during pregnancy; and they were not involved in environmental or socio-political groups but did participate in sociocultural groups. The vast majority of children (94.9 and 89.8%) did not own or use mobile phones at 8 years of age (Table 2). No significant differences were identified in relevant personal characteristics (sociodemographic characteristics or variables describing device use habits) between the subsample with in-home measurements and the full cohort that completed only the first questionnaire (Supplementary Table 2).

Overall, 87.3% and 97.9% of mothers had moderate to high (5-10) perceptions of ELF and RF exposure respectively and 79.2% (ELF) and 90.4% (RF) had moderate to high perceptions of the health-risk of such perception.

Table 2. Description of the study sample

Variables		N	%	Missing data
Variables of the children				
Sex	Female	194	50.1	0
	Male	193	49.9	
Owns a mobile phone	No	368	95.1	0
	Yes	19	4.9	
Uses a mobile phone[a]	No	342	89.8	6
	Yes	39	10.2	
Number of electronic devices used	0-7	373	96.4	0
	8-12	14	3.6	
Variables of the mother				
Social class	Manual	140	36.2	0
	Non-manual	247	63.8	
Educational level	Primary	35	9.1	1
	Secondary	140	36.3	
	University	211	54.7	
Age at child's birth, years	<25	3	0.8	0
	25-29	117	30.2	
	30-34	200	51.7	
	>34	67	17.3	
Country of birth	Spain	379	97.9	0
	Other	8	2.1	
Urbanicity	Urban	190	49.1	0
	Rural/Semi-urban	197	50.9	
Smoked during pregnancy	No	320	82.9	1
	Yes	66	17.1	
Used a mobile phone during pregnancy	No	4	1.1	11
	Yes	372	98.9	

Table 2 (continued)

Variables		N	%	Missing data
Number of children when cohort child was 8 years of age	1	104	26.9	1
	>1	282	73.1	
Participation in social groups related to environment or politics	None	350	90.7	1
	≥ 1 group	36	9.3	
Participation in sociocultural groups	None	171	44.3	1
	1 group	118	30.6	
	> 1 group	97	25.1	
Difficulty getting by financially	No	305	90.2	49
	Yes	33	9.8	
Has the feeling of living in a good neighborhood	Totally agree	189	49.0	1
	Fairly agree	161	41.7	
	Neither agree nor disagree	32	8.3	
	Somewhat disagree	3	0.8	
	Totally disagree	0	0.0	
	Do not want to answer	1	0.3	
Bothered by air pollution when opening the window	Not at all	184	47.7	1
	Occasionally	110	28.5	
	Sometimes	58	15.0	
	Often	26	6.7	
	Almost always	8	2.1	
Frequency of contact with relatives or friends	Almost daily	332	86.2	2
	At least once a week	45	11.7	
	1-3 times a week	5	1.3	
	<once a month	2	0.5	
	Rarely/never	1	0.3	
Previous miscarriages	No	317	81.9	0
	Yes	70	18.1	
Indoor exposure sources				
Number of electronic devices at home	0-17	354	91.5	0
	≥18	33	8.5	
Number of electronic devices that they use	0-9	366	94.6	0
	10-12	21	5.4	

Details of collected variables are explained in Supplementary Table 1;[a] Regular use of phone (at least once a week).

Perceptions of exposure levels decreased slightly (mean decreased in 0.7 points for both ELF and RF, but it was only significant for RF) but health-risk perceptions remained the same (means decreasing non-significantly by 0.2 for both ELF and RF fields) (Table 3). Median scores reported by mothers decreased for RF but not for ELF fields (Figure 2). Wilcoxon signed-rank test revealed that the distributions for exposure perception before and after knowing the results were different but were the same for health-risk perception (Wilcoxon signed-rank test p=0.010 and 0.003 for ELF and RF exposure perception respectively; p=0.462 and 0.333 for ELF and RF health-risk perception respectively).

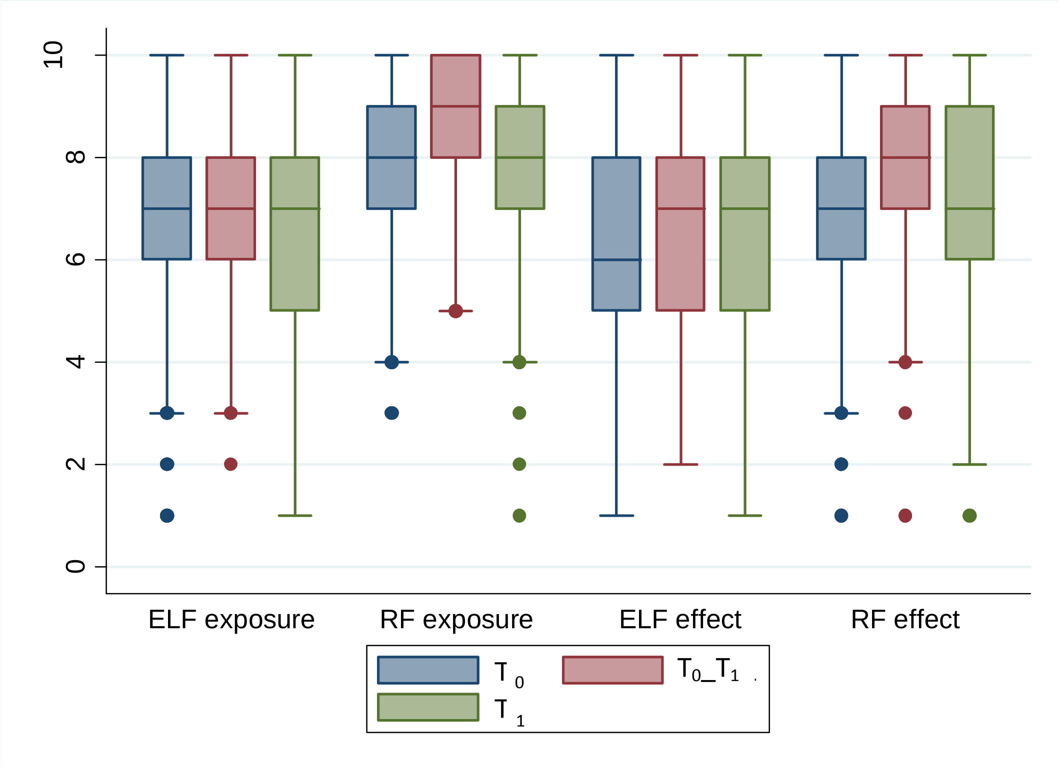

Figure 2: Scores reported by participants regarding exposure and health-risk perception, collected in different periods. T_0: individuals who only completed the first questionnaire, before knowing the exposure levels at home; T_0_T_1: individuals who completed both questionnaires, before knowing the exposure levels at home; T_1: individuals who completed both questionnaires, after knowing the exposure levels at home

Table 3

Mean and confidence Interval (95% CI) of exposure and health-risk perceptions before and after being informed about exposure levels at home and Spearman’s correlation between responses given at the two time points

Perception	N[a]	Mean (CI 95%) T_0	Mean (CI 95%) T_1	rho
ELF exposure	90	7.07 (6.68- 7.45)	6.37 (5.92- 6.82)	0.25*
RF exposure	90	**8.49 (8.21- 8.76)**	**7.76 (7.34- 8.17)**	0.19
ELF health-risk	88	6.45 (6.04- 6.87)	6.30 (5.89- 6.70)	0.29**
RF health-risk	89	7.46 (7.08- 7.84)	7.22 (6.79- 7.66)	0.51**

ELF: extremely Low Frequency; RF: radiofrequency; [a]N with data for both periods was considered for comparison; CI: confidence interval; T_0: Time of first questionnaire, before knowing the exposure levels at home; T_1: Time of second questionnaire, after knowing the exposure levels at home; rho: Spearman’s rank correlation coefficient; *p value<0.05; **p value<0.01; Significant differences between mean and confidence intervals at the two time points are indicted in bold

Table 4

Variation in responses between the first and second questionnaire (before and after being informed about exposure levels at home) regarding exposure and health-risk perception

	Increase		Decrease		Equal
	Mean (SD)	(%)	Mean (SD)	(%)	(%)
Exposure ELF	2.0 (1.4)	30.0	-2.0 (1.5)	48.9	21.1
Exposure RF	1.7 (1.0)	24.4	-2.4 (1.5)	48.9	26.7
Effect ELF	2.1 (1.2)	40.9	-2.1 (1.1)	47.7	11.4
Effect RF	1.7 (1.0)	37.1	-1.9 (1.3)	43.8	19.1

ELF: extremely low frequency; RF: radiofrequency; SD: standard deviation; %: percentage of participants that reported higher, lower or unchanged perception

Spearman's correlations between responses given to each of the four questions in the first questionnaire and in the second, related to both ELF and RF exposure and health-risk perceptions, were very weak to moderate (ranging from 0.2 to 0.5; Table 3). Most of the participants reported lower scores in the second questionnaire (range 44-49% for the different questions), while perceptions were higher in between 24 and 41% and remained unchanged in between 11 and 27% (Table 4).

Spearman's correlations between exposure and health-risk perceptions were moderate (ranged from 0.4 to 0.5), but were higher between perception of ELF and of RF exposure (ranging from 0.6 to 0.7) and between health-risk of ELF and RF fields (0.7) (Table 5).

Table 5

Spearman's correlation between different perceptions regarding exposure and health-risk of extremely low frequency and radiofrequency fields

	T	N	rho
ELF Exposure - RF Exposure	T_0	385	0.61
ELF Exposure - RF Exposure	T_1	90	0.74
ELF Effect - RF Effect	T_0	385	0.70
ELF Effect - RF Effect	T_1	88	0.69
ELF Exposure - ELF Effect	T_0	383	0.42
ELF Exposure - ELF Effect	T_1	88	0.44
RF Exposure - RF Effect	T_0	383	0.49
RF Exposure - RF Effect	T_1	89	0.39

ELF: extremely low frequency; RF: radiofrequency; T: Time of questionnaire; rho: Spearman's rank correlation coefficient; T_0: Time of first questionnaire, before knowing the exposure levels at home; T_1: time of second questionnaire, after knowing the exposure levels at home; p value<0.01 in all cases

Higher perceptions of exposure and risk were not associated with higher exposure levels measured at home (Table 6). Median perceptions in relation to sociodemographic characteristics, device use and proximity to outdoor EMF sources are summarized in Supplementary Table 3. Based on the bivariate analysis, the variables with a p value below 0.2 that were included in the models varied between the type of perception considered, but included: variables of the children (owning a mobile phone; mobile phone calls; number of devices used); variables of the mother (age at child's birth; social class; educational level; and type of area where they live; mobile phone use during pregnancy; smoking during pregnancy; involvement in groups related to the environment or politics; involvement in sociocultural groups; having the feeling of living in a good neighborhood; being bothered by air pollution when opening the window; difficulty getting by financially; previous miscarriages; intelligence of the mother [only in sensitivity analysis]; negative feelings of the mother [feeling of lack of control and lack of happiness]; and mental health of the mother as assessed with the SCL-90-R and GHQ-12 [only in sensitivity analysis]); and variables related to indoor and outdoor exposure sources (having WiFi at home; number of devices at home; devices regularly use at home; mobile phone antenna within 300 and 600 meters of the home; television antenna within 600 meters of the home; very high voltage power lines and high and medium voltage underground and both over- and underground power lines within 150 meters of the home). Variables that were not included in the models were: poor dietary habits of the children; country of birth of the mother; parity; frequency with which the mother had contact with relatives and friends; cordless phone at home; and high and medium voltage overhead power lines within 150 meters.

Table 6

Measured ELF and RF exposure levels at home and mother's perceptions

			Exposure levels at home[a]		
		Median (N)[a]	<Median	≥Median	p
Exposure perception T_0					
	ELF	≤Median, 7 (N=55)	26 (47.3)	29 (52.7)	0.488
		>Median, 7 (N=47)	19 (40.4)	28 (59.6)	
	RF	≤Median, 8 (N=53)	26 (49.1)	27 (50.9)	0.924
		>Median, 8 (N=50)	25 (50.0)	25 (50.0)	
Health-risk perception T_0					
	ELF	≤Median, 7 (N=44)	20 (45.5)	24 (54.5)	0.873
		>Median, 7 (N=57)	25 (43.9)	32 (56.1)	
	RF	≤Median, 8 (N=69)	37 (53.6)	32 (46.4)	0.290
		>Median, 8 (N=33)	14 (42.4)	19 (57.6)	
Exposure perception T_1					
	ELF	<Median, 7 (N=42)	18 (42.9)	24 (57.1)	0.977
		≥Median, 7 (N=47)	20 (42.6)	27 (57.4)	
	RF	≤Median, 8 (N=51)	27 (52.9)	24 (47.1)	0.523
		>Median, 8 (N=39)	18 (46.2)	21 (53.8)	
Health-risk perception T_1					
	ELF	<Median, 7 (N=41)	18 (43.9)	23 (56.1)	0.807
		≥Median, 7 (N=46)	19 (41.3)	27 (58.7)	
	RF	≤Median, 7 (N=45)	21 (46.7)	24 (53.3)	0.597
		>Median, 7 (N=44)	23 (52.3)	21 (47.7)	

ELF: extremely low frequency; RF: radiofrequency; T_0: Time of first questionnaire, before knowing the exposure levels at home; T_1: Time of the second questionnaire, after knowing the exposure levels at home; [a]Criteria for participants' distribution into groups was based on equitability, dividing the sample into two groups as similar as possible regarding the number of individuals in each of the groups; [b]For ELF, 24-hour long measurements at home was considered and for RF mean exposure from spot measurements. Measurements were taken in the living room and child's bedroom.

Manual social class, living in an urban area, having the feeling of living in a good neighborhood and often being bothered by air pollution when opening a window were associated with higher perceptions in more than one question. In contrast, being older and having more devices at home were associated with lower perceptions (Table 7). Factors that most affected perceptions in terms of score were difficulty getting by financially (β=2.33, CI 95%: 0.61-4.04, for perception of RF health-risk in the second questionnaire) and number of devices at home (those who had more than 18 devices having 1.6 and 2.1-fold lower perception of ELF and RF health-risk in the second questionnaire respectively). Including maternal mental health and intelligence did not have any effect on any of the perception scores, with the exception of RF exposure perception in the first questionnaire, which increased slightly with increasingly poor mental health (β=0.05, CI 95%: 0.01-0.10; Supplementary Table 4).

No agreement was found between beliefs of the participants regarding whether there was WiFi in their child’s school and actual presence of WiFi in the schools (Cohen´s kappa 0.05). Many mothers (42%) did not know whether there was WiFi or not in their child’s school. Among those who responded, schools with WiFi were adequately identified (92% of schools with WiFi were well detected), whereas most of the schools without WiFi (85.7%) were believed to have WiFi by participants (data not shown).

The vast majority of participants (94.4%) claimed that they had received no or insufficient information from public bodies (0-4 on the 10-point scale) and 96.7% considered it very important that they should (7-10 on the 10-point scale).

Table 7 Results of multiple linear regression models with perception levels as dependent variables

Variables	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
	β (95% CI)							
Social class								
Non-manual			Reference		Reference	Reference		
Manual			**0.46 (0.04 to 0.88)**		**1.11 (0.17 to 2.04)**	**1.05 (0.18 to 1.92)**		
Type of area								
Rural/Semi urban	Reference	Reference						
Urban	**0.53 (0.16 to 0.91)**	**0.32 (0.01 to 0.63)**						
Smoking								
No							Reference	
Yes							**-1.42 (-2.75 to -0.08)**	
MP antenna≤300m								
No								
Yes								
Sociocultural groups								
0 groups	Reference							
1 group	-0.08 (-0.50 to 0.36)							
> 1 group	**0.54 (0.07 to 1.01)**							
Groups related to environment or politics								
None			Reference					
≥ 1 group			**0.76 (0.07 to 1.45)**					

Table 7 (continued)

Variables		ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1 β (95% CI)	RF exp T_1	ELF effect T_1	RF effect T_1
Good neighborhood to live in									
	Totally agree	Reference	Reference						
	Fairly agree	**0.49 (0.10 to 0.88)**	0.32 (-0.01 to 0.64)*						
	Neither agree nor disagree	0.47 (-0.23 to 1.18)	0.34 (-0.24 to 0.93)						
	Somewhat disagree	0.40 (-1.74 to 2.54)	0.17 (-1.59 to 1.93)						
	Totally disagree	-	-						
	Do not want to answer	1.78 (-1.81 to 5.36)	1.83 (-1.19 to 4.85)						
Bothered by air pollution when opening the window									
	Not at all	Reference		Reference	Reference				
	Occasionally	0.11 (-0.32 to 0.55)		0.02 (-0.45 to 0.48)	0.08 (-0.37 to 0.53)				
	Sometimes	-0.08 (-0.63 to 0.47)		-0.29 (-0.88 to 0.30)	-0.08 (-0.66 to 0.51)				
	Often	**1.10 (0.32 to 1.88)**		**1.17 (0.35 to 1.99)**	**1.26 (0.48 to 2.05)**				
	Almost always	0.52 (-0.79 to 1.83)		0.80 (-0.60 to 2.21)	0.50 (-0.85 to 1.85)				

Table 7 (continued)	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
Variables	β (95% CI)							
Age of the mother at birth of the child, years								
<25					-	-		-
25-29					Reference	Reference		Reference
30-34					-0.66 (-1.62 to 0.30)	-0.56 (-1.43 to 0.37)		**-1.05 (-2.04 to -0.07)**
≥35					**-1.88 (-3.23 to -0.52)**	**-1.88 (-3.15 to -0.62)**		**-1.45 (-2.84 to -0.06)**
Children's number of mobile phone calls of children								
<1 at week				Reference				
≥ 1 at week				**-0.64 (-1.28 to -0.00)**[a]				
Electronic devices at home								
0-17							Reference	Reference
>18							**-1.60 (-2.81 to -0.39)**	**-2.10 (-3.42 to -0.78)**
WiFi at home								
No					Reference		**Reference**	
Yes					-1.40 (-2.82 to 0.01)**		**1.49 (0.15 to 2.83)**	
Difficulty getting by financially								
No								Reference
Yes								**2.33 (0.61 to 4.04)**

Table 7 (continued)

Variables	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
	β (95% CI)							
DVBT antenna≤600 m								
None			Reference					
≥ 1			**-0.68 (-1.23 to -0.13)**					
High (30 kV) and medium (13.2 kV) voltage power lines ≤150 meters, Both over- and underground								
None	Reference							
≥ 1	**0.39 (0.02 to 0.77)**							
Transformer Stations (from 13.2 kV to 250-300 V) ≤50 meters								
None	Reference							
≥ 1	**0.49 (0.09 to 0.88)**							

ELF: extremely low frequency; RF: radiofrequency; T_0: Time of first questionnaire, before knowing the exposure levels at home; T_1: Time of second questionnaire, after knowing exposure levels at home; exp: exposure; *p=0.055; **p=0.051; CI: Confidence interval; dashes (-) mean that there are no individuals in that category; [a]95% CI: 1.28to 0.03; there are empty spaces because variables included in the models depended on the perception asked

DISCUSSION

In this study, we examined perceived exposure to EMFs and perceived health-risk perception due to such exposure in the mothers of a birth cohort, we assessed the impact on these perceptions of providing information on exposure, and we explored possible explanatory variables. Overall, very high perceptions were found for both exposure and health-risk and for both ELF and RF fields, with mean and medians around 7-8 on the 10-point Likert-scale. Providing information did not alter health-risk perception, but mean exposure perception decreased by 0.7 points, although it was only significant for RF and not for ELF. Variables that were repeatedly associated with higher perceptions included manual social class, living in an urban area, having the feeling of living in a good neighborhood, often being bothered by air pollution when opening a window, being younger and having fewer devices at home.

Generally, risk perceptions were found to be very high. Lower overall exposure perception [14] and health-risk perception [1] were found in previous studies (less than half the maximum score). Compared to respondents to the 2010 Eurobarometer survey [15], and despite differences between the studies, our sample was similarly concerned about health-risks of ELF fields and more concerned about the health-risks of RF fields. Specifically, 79.2% and 90.4% of the participants in our study believed that ELF and RF fields respectively may have negative health effects (with ratings of more than 5 points on a 10 point scale), while in the European study, 80.0% and 75.0% of Spanish and 70.0% and 70.0% of European respondents believed that high voltage power lines and mobile phone antennas affect their health to a large or some extent. Concerns in our population were higher for exposure than for health-risk and, in contrast to other studies, higher for RF than for ELF fields [15,16].

Unlike health-risk perception, overall exposure perception decreased slightly, by 0.7 points, from the first questionnaire to the second. The information that we provided to families was related to the exposure levels found in their home and we stated that the exposure observed was far below the levels permitted by the Spanish regulation [17,18]. Consequently, it is understandable that that information rebounded only in exposure perception. Interestingly, however, Freudenstein et al. (2015) found that individuals associated health-risk with time of the day and frequency of device use, whilst strength of exposure did not play any role in health-risk perception [19].

Correlations between responses to the same questions in the first and the second questionnaire were very weak to moderate (ranging from 0.2 to 0.5, lowest for perception of RF exposure and highest for perception of RF health-risk). Even though almost half of the participants reported being less concerned (lower scores) in the second questionnaire, up to 41% and to 27% were more or equally concerned respectively. Previous studies have found that people change their answers when asked the same questions concerning risk at different times, showing that risk perception is not stable [20,21]. It would have been useful to including a control population consisting of a subsample that did not receive information concerning exposure levels in their homes to assess the stability of responses in this study. In contrast, if we assume that information was the key variable that dominated changes in response, we could hypothesize: a) people do not trust information provided by public bodies, noting that the INMA-Gipuzkoa research project is led by the Public Health Authority of Gipuzkoa; or b) providing information has the opposite effect to that intended, by increasing people's awareness. In line with this, providing information has shown contradictory effects in previous studies in relation to EMFs [5,6,22–25].

Perception was more sensitive to the type of question/effect (exposure or health-risk perception) than to the type of exposure (ELF or RF fields) of interest. This means that even if individuals think that they are exposed to high ELF or RF fields, they do not necessarily think that such exposure poses a high risk to their health, and vice versa. The correlation in this case was moderate and similar to that found in previous research [19]. In contrast, individuals that think ELF exposure is high, rate RF exposure similarly highly and the same is true for health-risk. Indeed, there is an increasing trend to be concerned about health implications of all kinds of environmental factors [1]. Hence, it was also reasonable to expect that in this study those who were often bothered by air pollution when opening a window would score higher in perception. Yet, this trend did not appear for women that were always bothered by air pollution when opening a window and the interpretation of this result is unclear.

Exposure to EMFs is not as intuitive as exposure to other environmental factors. This might be the reason underlying the lack of correlation between exposure levels measured at home and exposure perception. In line with this, Martens et al., (2017) found very weak correlation between modeled and perceived exposure [26]. This is important, because perceived exposure can be a predictor of non-specific symptoms and sleep disturbances, while actual exposure has not been related to such symptoms [14,26–28].

Understanding the key factors that explain perceptions in a population are crucial for developing adequate risk communication strategies and interpreting indirect health effects related to EMF exposure through risk perception [29]. In our study, manual social class, living in an urban area, often being bothered by air pollution when opening a window, being younger and having fewer devices at home were associated with higher perceptions. Specifically, and in contrast to the Eurobarometer survey [15], we found that manual social class increased significantly some of the concerns (from 0.4 to 1.1 points higher).

Living in urban areas explained somewhat higher exposure perceptions in the first questionnaire. People living in such areas probably assume that they are more exposed to mobile phone antennas and other EMF sources. Visualization of the sources may be a factor, as people living in urban areas continuously see mobile phone antennas on roofs. This may make them believe they are more exposed, regardless of technical issues concerning power of the antennas, which can indeed sometimes result in higher exposures from the mobile phones in rural areas [30]. Even though they are familiar with the sources and this could lessen concerns, it is an imposed factor, that is, the risk is not taken voluntarily and thus there is a lack of personal control of the risk, this potentially resulting in a higher perception of exposure. In our study, proximity to mobile phone antennas (≤300 meters) was not however associated with a higher perception and having at least one television antenna (≤600 meters) was associated with a lower perception of RF health risk. Nevertheless, Baliatsas et al. (2011) observed that while actual distance to these type of antennas and to power lines was not associated with non-specific physical symptoms, perceived proximity it was [31].

In our study, younger mothers demonstrated greater levels of concern in most of the questions of the second survey. This is in line with some previous studies [29] but contradicts other research which had the opposite results [15] or found no differences by age [32].

It is difficult to explain why having the feeling of living in a good neighborhood explains higher exposure perception. We might expect the contrary, that is, if individuals feel comfortable in their neighborhood, they might believe that generally positive factors are governing that feeling. Besides, the observed higher levels were attributable only to the response “fairly agree” with the statement while rest of the categories (totally agree; neither agree nor disagree; somewhat disagree; totally disagree) did not explain any change in perceptions. Further, this factor was only significant for one of the questions and was very general; and hence, the interpretation of this result is unclear.

The directionality of having WiFi at home is also not clear. While having WiFi increased perceiving health-risk effects of RF to a higher extent, decreased ELF exposure perception (although the p value was 0.051).

Difficulty getting by financially was the factor that affected perceptions most strongly, (in that it was associated with a larger change in score, 2.33), but this only happened for perception of RF health-risk in the second questionnaire. The next factor that explained more in terms of score was the number of devices at home. Those who had more than 18 devices reported 1.6- and 2.1-fold lower perception of ELF and RF health-risk in the second questionnaire respectively. This could be related to the familiarity with the sources and the fact that is a personal decision.

Although education has been mentioned by previous publications as an explanatory variable [15,20,33], differences between individuals with different levels of education were not significant.

Even though the subsample with measurements and hence who completed two questionnaires did not differ from the whole sample in the characteristics considered, it seems that different variables were related to perceptions reported in the two periods. This might be due to the reception of information affecting the factors involved.

Our study has some strengths including detailed information regarding individual maternal characteristics that allow us to check whether perceptions are related to sociodemographic characteristics. Further, unlike our work, most studies assessing EMF perception have focused on RF fields, and few studies have considered together exposure and health-risk perception for both ELF and RF fields [5,14].

We performed measurements in a representative sample and assessed the association between measured and perceived levels of exposure. Furthermore, participants completed the questionnaire at two time points, before and after being aware of their exposure levels, and this allowed us to explore the usefulness of providing information for decreasing lay people’s concerns. To our knowledge, this is the first study assessing perception before and after receiving information regarding personal exposure levels at home.

Limitations of the study include that all participants were women. Hence, our sample may not be representative of the entire population. It is well known that women tend to report higher levels of concerns [34–36].

Further, the fact that they are involved in a cohort study may have altered their attitude towards environmental exposure, increasing their awareness. Further, the fact that both exposure and health effects are the subject of research could in itself increase concerns, as they might feel that this implies that EMFs are something to fear [25,37].

Since perception is a little-known world, we might not have included all variables that are related to that perception. Nevertheless, we considered a broad range of sociodemographic variables that have most often been related to perception together with other variables that we considered important.

Our questions regarding perceptions were very general. Thus, it is not possible to make detailed interpretation of results, and a more thorough assessment of perceptions, with more specific questions, would be necessary to improve our understanding of people's concerns regarding environmental exposure. In the survey, we grouped all types of RF sources and similarly all types of ELF sources together. On the other hand, as lay people's attitude towards different sources may differ, it would be desirable to assess perception to different sources independently for a better understanding of the factors involved. For example, Freudenstein et al. (2015) found that mobile phone base stations were considered the highest contributors to exposure, while people underestimated the contribution of mobile phones. Generally, people are more afraid of far-field than near-field sources [1,19].

Furthermore, measured levels of exposure were very low compared to reference levels [17,38] and thus this study is limited to a population with low exposure levels. In addition, even that we differentiated between urban or rural/semi-urban areas, the municipality with highest population in the study area has less than 15,000 inhabitants. Therefore, it is also limited to small urbanized areas.

On the other hand, using a Likert-type scale can also have inherent limitations. People may prefer some numbers to others and there can be a tendency to avoid extreme values. This would partly explain the median scores (range 6-9, most often 7) we obtained in this study.

Unquestionably, our participants thought they received no or insufficient information from public bodies and considered it very important that they should. As mentioned, providing information had an effect, though small, on awareness. The way information is given may affect the responses. Over recent decades, significant progress has been made regarding transparency in government and public bodies [39]. Continuous dissemination of up-to-date scientific evidence by public bodies and scientific agencies may be part of the solution to make citizens feel more confident about the information provided by public administrations and to be more familiar with the data, resulting in more reason-based perceptions. It is critical, however, that this information is given in an effective manner and addressed to lay people, in order to increase their knowledge on the subject without increasing levels of concerns.

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SUPPLEMENTARY MATERIAL

Supplementary Table 1. Description of the independent variables studied and how they were assessed

	Variable	Additional description	Categories used for analysis	Collection period
Variables of the children	Owns a mobile phone	Mothers answered the question: “Does your child have a mobile phone (consider their own mobile phone or a mobile phone shared with a brother/sister or some other family member)?”	Yes or no	When the child was 8 years of age
	Uses a mobile phone (calls made)	Mothers answered the question: “How many calls does your child make with a mobile phone (refers to all mobile phones, not just their own mobile phone)”. Possible answers were: Never; Less than once a week; Once a week or more; Don´t know. They were grouped into to two categories; No (meaning that they use less than once a week or never) and Yes (at least once a week)	Yes or no	When the child was 8 years of age
	Number of electronic devices used	This variable was constructed by adding number of devices used by children. The mothers selected the devices used by their children from a list that included: TV; computer; iPod or similar; music system; DVD; electronic book; electric blanket; hair dryer; electric toothbrush; tablet; laptop; game console. Based on the sum, participants were categorized into two groups	0-7; 8-12	When the child was 8 years of age
	Poor dietary habits	A combination of four questions was used for the creation of this variable: 1) Eats prepared food from supermarket 2) Eats organic/ecological food 3) Visits a fast-food restaurant /-take-away 4) Caffeinated or "energy" drinks (e.g. Coca-Cola, Diet Coke, Red Bull) The possible answers for each of the questions were: 1-Never; less than once a month; 2-between one and three times a month; 3- once a week; 4-between two and four times a week; 5-between five and six times a week; 6-daily. The question “2” was inverted and the punctuation of the four questions was added, obtaining a numerical variable, which was higher when the dietetic habits were poorer	Numerical score, from 6 to 24	When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
Sociodemographic characteristics	Age of the mother at child's birth	Recorded as a discrete numerical variable and categorized into four groups	<25; 25-29; 30-34; ≥35	At the child's birth
	Social class	This variable was constructed from the type of work of the mother, classified according to the Spanish National Classification of Occupations (CNO94) [40] into five levels which were then grouped into two categories: the manual or lower class (IV and V) and the skilled non-manual, or higher class (I-III)	Manual or non-manual	At pregnancy
	Educational level		Primary; secondary; university-level	At pregnancy
	Urbanicity	The mothers' place of residence was classified as follows: an area with a population of more than 10,000 was considered urban, between 2,000 and 10,000 semi-urban and below 2,000 rural. It was categorized into two groups	Rural/semi-urban; urban	When the child was 8 years of age
	Country of origin		Spain; Other	At pregnancy
	Smoked during pregnancy	Recorded using 5 categories: no-smoker; ex-smoker and before occasional; ex-smoker and before habitual; casual smoker; smoker. These were then grouped into two categories; smoker or non-smoker	Yes or no	At pregnancy
	Number of children of the mother	Recorded as a discrete numerical variable and categorized into two groups	1; >1	When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
	Participation in social groups related to environment or politics	Mothers indicated whether they participated in environmental organizations, labor unions or political parties. The response was categorized into two groups	None or ≥ 1 group	When the child was 8 years of age
	Participation in sociocultural groups	The initial question was whether they participated (yes or no) in: environmental organizations; labor unions; political parties; parents associations; home owners' association; art or music groups; religious group; charities; youth groups; women's associations; social clubs; sport clubs; game groups; other group. The sum was categorized into three groups	0; 1 or >1 groups	When the child was 8 years of age
Sociodemographic characteristics	Difficulty getting by financially	Personal perception	Yes or no	When the child was 8 years of age
	Has the feeling of living in a good neighborhood		Totally agree; Fairly agree; Neither agree nor disagree; Somewhat disagree; Totally disagree; Do not want to answer	When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
	Bothered about opening the window due to air pollution	The question was: To what extent does air pollution bother you if you leave the window open (we refer to gases, fumes, dust, etc. of traffic, industry, etc.)?	Not at all; Occasionally; Sometimes; Often; Almost always	When the child was 8 years of age
Sociodemographic characteristics	Frequency of contact with relatives or friends		Almost daily; At least once a week; 1-3 times a week; <once a month; Rarely/never	When the child was 8 years of age
	Negative feelings	A combination of four questions was used for the creation of the variable: 1) In the last month, how often have you felt unable to control the important things in your life? 2) In the last month, how often have you felt confident in your ability to manage your personal problems? 3) In the last month, how often have you felt that things were going the way you wanted them to? 4) In the last month, how often have you felt that the difficulties accumulate so much that you cannot overcome them? The possible answers for each of the questions were: 1-never; 2-almost never; 3-sometimes; 4-quite often; 5-very often. Summing the scores of questions 1 and 4 and subtracting those of questions 2 and 3, we obtained a numerical score, which was higher when the feeling of control and good feelings were poorer.	Numerical score, from 4 to 20	When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
Health-related issues of the mother	Previous miscarriages	Mothers reported whether they had had any miscarriages before the birth of the cohort child	Yes or no	At pregnancy
	General mental score (Mental health)	Assessed with General Health Questionnaire (GHQ-12) [11], which seeks to identify psychological stress and short-term changes in mental health; the higher the score, the poorer the mental health	Numerical score	When the child was 14 months of age
	Global severity index	Assessed with Symptom Checklist 90 Revised (SCL-90-R) [12], which measures recent psychopathological or psychosomatic alterations; the higher the score, the greater the number of symptoms	Numerical score	When the child was 4 years of age
	Intelligence of the mother	Assessed with Wechsler Adult Intelligence Scale-Third edition [13]		When the child was 4 years of age
Indoor exposure sources	Electronic devices at home	Mothers selected the devices they had at home from a list of devices: television; cordless phone; dish washer; video; PSP PlayStation Portable (PSP); WiFi router; music system; speaker; piped music; computer; scanner; printer; fridge; freezer; extractor hood; induction hob; ceramic hob; oven; microwave; washing machine; tumble dryer; air conditioner. The sum was categorized into 2 groups (below and above or equal to the 95th percentile)	0-17; ≥18	When the child was 8 years of age
	Electronic devices used	Mothers selected the devices they use regularly at home (at least once a week) from a list of devices: vacuum cleaner; mixer; coffee maker; iron; toaster; juicer/blender; steam cleaner; griddle; electric shaver; hair dryer; straightener/curling iron; electric toothbrush; electric alarm; fryer. The sum was categorized into 2 groups (below and above or equal to the 95th percentile)	0-9; 10-12	When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
Indoor exposure sources	WiFi at home		Yes or no	When the child was 8 years of age
	WiFi at school	Mothers reported whether there was WiFi or not in their children's school and this was compared with data provided by school principals	Yes;no; I don't know (for mothers); Yes or no for school principals	
	Cordless phone (DECT) at home		Yes or no	When the child was 8 years of age
Outdoor exposure sources	DVB-T antenna locations	Location of broadcast antennas was provided by companies operating in the area. We assessed whether there were any antenna within 300 or 600 meters of each home	<300 meters: yes or no <600 meters; yes or no	When the child was 8 years of age
	FM radio antenna locations			When the child was 8 years of age
	Mobile phone base stations location	We used an application of the Spanish Ministry of Energy, Tourism and Digital Agenda to identify locations of mobile phone base stations (https://geoportal.minetur.gob.es/VCTEL/vcne.do)		When the child was 8 years of age

Supplementary Table 1 (continued)

	Variable	Additional description	Categories used for analysis	Collection period
Outdoor exposure sources	Very high voltage (132 kV) power lines within 150 meters	Number of this type of source within 150 meters of each home was provided by companies operating in the area	None; Some	When the child was 8 years of age
	High (30 kV) and medium (13.2 kV) voltage power lines within 150 meters Overhead Underground Both over- and underground		None; Some	When the child was 8 years of age
	Transformer Stations (from 13.2 kV to 250-300 V) within 50 meters	Number of this type of source within 50 meters of each home was provided by companies operating in the area	None; Some	When the child was 8 years of age

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Supplementary Table 2

Characteristics of the participants in the subsample with measurements in their homes and the entire cohort members

	Children with in-home measurements (n=104) n (%)	Children with no measurements(n=293) n (%)	p[a]
Variables of the children			
Sex			
Female	47 (45.2)	153 (52.2)	0.218
Male	57 (54.8)	140 (47.8)	
Owns a mobile phone at 8 years of age[b]			
No	101 (98.1)	257 (93.5)	0.075
Yes	2 (1.9)	18 (6.5)	
Uses a mobile phone at 8 years of age[c]			
No	89 (87.3)	254 (90.7)	0.323
Yes	13 (12.7)	26 (2.3)	
Number of electronic devices			
0-7	99 (96.1)	275 (96.5)	0.534
8-12	4 (3.9)	10 (3.5)	
Variables of the mother			
Age at child’s birth, years			
<25	0 (0.0)	4 (1.4)	0.275
25-29	30 (28.9)	92 (31.4)	
30-34	60 (57.7)	143 (48.8)	
>35	14 (13.5)	54 (18.4)	
Country of birth			
Spain	103 (99.0)	284 (96.9)	0.465
Other	1 (1.0)	9 (3.1)	
Social class			
Non-manual	72 (69.2)	177 (60.4)	0.110
Manual	32 (30.8)	116 (39.6)	
Educational level			
Primary	7 (6.7)	33 (11.3)	0.065
Secondary	31 (29.8)	111 (38.1)	
University	66 (63.5)	147 (50.5)	
Type of area			
Rural/No urban	54 (51.9)	151 (51.5)	0.946
Urban	50 (48.1)	142 (48.5)	
Number of children			
1	10 (9.6)	26 (9.1)	0.874
>1	94 (90.4)	260 (90.9)	
Smoking habits			
No	91 (87.5)	234 (80.1)	0.093
Yes	13 (12.5)	58 (19.9)	

Supplementary Table 2 (continued)

	Children with in-home measurements (n=104) n (%)	Children with no measurements(n=293) n (%)	p^a
Sociocultural groups			
0 groups	39 (37.5)	139 (47.6)	0.172
1 group	38 (36.5)	83 (28.4)	
> 1 group	27 (26.0)	70 (24.0)	
Groups related to environment or politics			
None	94 (90.4)	266 (91.1)	0.828
≥ 1 group	10 (9.6)	26 (8.9)	
Feeling of living in a good neighborhood			
Totally agree	52 (50.0)	141 (48.3)	0.526
Fairly agree	44 (42.3)	122 (41.8)	
Neither agree nor disagree	6 (5.8)	26 (8.9)	
Somewhat disagree	2 (1.9)	1 (0.3)	
Totally disagree	0 (0.0)	1 (0.3)	
Do not want to answer	0 (0.0)	1 (0.3)	
Being bothered about opening the window due to air pollution			
Not at all	52 (50.0)	138 (47.3)	0.696
Occasionally	30 (28.9)	81 (27.7)	
Sometimes	12 (11.5)	49 (16.8)	
Often	7 (6.7)	19 (6.5)	
Almost always	3 (2.9)	5 (1.7)	
Difficulty getting by financially			
No	76 (93.8)	235 (88.7)	0.179
Yes	5 (6.2)	30 (11.3)	
Contact with friends and familiars			
Almost daily	86 (82.7)	254 (87.0)	0.259
At least once a week	18 (17.3)	29 (9.9)	
1-3 times a week	0 (0.0)	5 (1.7)	
<once a month	0 (0.0)	2 (0.7)	
Rarely/never	0 (0.0)	1 (0.3)	
Previous miscarriages			
No	83 (79.8)	242 (82.6)	0.526
Yes	21 (20.2)	51 (17.4)	
Indoor sources			
WiFi at home			
No	9 (8.7)	18 (6.3)	0.422
Yes	95 (91.3)	267 (93.7)	
Cordless phone at home			
No	23 (22.8)	82 (29.3)	0.209
Yes	78 (77.2)	198 (70.7)	

Supplementary Table 2 (continued)

	Children with in-home measurements (n=104)	Children with no measurements(n=293)	
	n (%)	n (%)	p[a]
Electronic devices at home			
0-17	90 (87.4)	265 (93.0)	0.081
≥18	13 (12.6)	20 (7.0)	
Regular use of electronic devices at home			
0-9	96 (93.2)	271 (95.1)	0.469
10-12	7 (6.8)	14 8 (4.9)	
Outdoor sources			
Mobile Phone Base Station ≤ 300 m			
None	88 (84.6)	255 (87.0)	0.537
≥1	16 (15.4)	38 (13.0)	
Mobile Phone Base Station ≤ 600 m			
None	40 (38.5)	105 (35.8)	0.633
≥1	64 (61.5)	188 (64.2)	
DVB-T (television) antenna ≤ 600 m			
None	88 (84.6)	248 (84.6)	0.995
≥1	16 (15.4)	45 (15.4)	
Very high voltage (132 kV) power lines within 150 meters			
None	104 (100.0)	289 (99.0)	0.299
≥1	0 (0.0)	3 (1.0)	
High (30 kV) and medium (13.2 kV) voltage power lines ≤150 meters			
Overhead			
None	85 (81.7)	247 (84.6)	0.497
≥1	19 (18.3)	45 (15.4)	
Underground			
None	36 (34.6)	112 (38.4)	0.498
≥1	68 (65.4)	180 (61.6)	
Both over- and underground			
None	60 (57.7)	150 (51.4)	0.267
≥1	44 (42.3)	142 (48.6)	
Transformer Stations (from 13.2 kV to 250-300 V) ≤50 meters			
None	76 (73.1)	194 (66.4)	0.212
≥1	28 (26.9)	98 (33.6)	

[a] Differences were tested using chi-square test. However, when expected counts were below 5, Fisher's exact test was used. Level of significance was 0.05; [b] It can be either a personal phone or a phone shared with any member of the family; [c] Regular use of phone (at least once a week).

Supplementary Table 3. Median perception levels by sociodemographic characteristics, use of devices and proximity to EMF sources

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Variables of the children																		
Owns a mobile phone																		
No	336	7	0.9855	8	0.3036	6	**0.1556**	8	**0.0412**	81	7	0.3217	8	0.4170	7	**0.0798**	8	0.2862
Yes	40	7		8		6		7		8	5.5		8		6		7	
Mobile phone calls made by the child																		
<1 per week			0.7979		0.2113		**0.1474**		**0.0596**			0.3217		0.4170		**0.0798**		0.2862
≥1 per week																		
Use of electronic devices children																		
0-7	373	7	0.3828	8	**0.0945**	6	0.8937	7	0.5525	86	7	0.4322	8	0.2764	7	0.6692	7	0.5741
8-12	14	7.5		9		6		8		4	8		9.5		7		8.5	
Variables of the mother																		
Age of the mother at the child's birth, years																		
<25	3	7	0.8391	7	0.5662	6	0.7689	6	0.8477									
25-29	117	7		8		6		8		26	7	**0.1046**	8.5	**0.0510**	7	**0.1383**	8	**0.0346**
30-34	200	7		8		6		7		51	7		8		7		7	
>35	67	7		8		7		7.5		13	5		7		6		7	
Country of birth																		
Spain	377	7	0.4793	8	0.9319	6	0.7937	7	0.7173	90								
Other	8	7.5		8.5		6.5		7.5		0								
Social class																		
Non-manual	247	7	0.3480	8	0.6940	6	**0.0298**	7	0.2245	64	6	**0.0146**	8	**0.0124**	6	0.8362	7.5	0.7672
Manual	140	7		8		7		8		26	8		9		7		7	

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Educational level																		
Primary	35	7	0.6488	9	**0.1054**	7	**0.1437**	7	0.6046	5	8	**0.1616**	70	**0.1136**	6	0.6380	6	**0.0843**
Secondary	140	7		8		7		8		27	7		9		7		8	
University	211	7		8		6		7		58	6		8		6		7	
Type of area																		
Rural/No urban	197	7	**0.0039**	8	**0.0120**	6	0.5084	7	0.2192	45	6	0.6171	8	0.5316	6	0.6533	7.5	0.3802
Urban	190	7		9		7		8		45	8		9		7		7	
Mobile phone use during pregnancy																		
No	4	7	0.7460	9.5	**0.1346**	5.5	0.5934	6	**0.1753**		0							
Yes	372	7		8		6		7			86							
Number of children at 8 years of the child																		
1	104	7	0.7754	8	0.6589	6	0.8195	8	0.7449	19	7	0.3081	8	0.6829	6	0.9877	7	0.7880
>1	282	7		8		6		7		71	7		8		7		8	
Smoking in pregnancy																		
No	320	7	0.7485	8	0.2177	6	0.6343	7	0.7855	81	7	0.8914	8	0.5832	7	**0.0622**	8	**0.0617**
Yes	66	7		9		6		7		9	6		8		5.5		6	

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Participation in groups related to environment or politics																		
0	350	7		8		6		7		83	7		8		7		7	
1	32	7	0.4025	9	0.7402	7	**0.0993**	7.5	0.6497	5	6	0.8268	8	0.7343	7	0.9119	7	0.8634
>1	4	6.5		9		6		7		2	6		7.5		6		8	
Participation in sociocultural groups																		
0	178	7		8		6		7		35	7		9		7		7	
1	118	7	**0.1715**	8	0.6179	6	0.6227	7	0.8302	32	6	0.7722	8	0.5780	6	0.6611	7.5	0.9571
>1	97	7		9		7		7.5		23	6		8		6.5		7.5	
Good neighborhood to live in (feeling)																		
Totally agree	189	7		8		6		7		45	6		8		7		8	
Fairly agree	161	7		8		7		8		37	7		8		6.5		7	
Neither agree nor disagree	32	7	**0.1356**	8	0.2267	6	0.2910	8	**0.0876**	6	6	0.9131	8	0.7673	6	0.7945	8	0.8509
Somewhat disagree	3	7		8		6		9		2	6		7		7		6.5	
Totally disagree	1									0								
Bothered by air pollution when opening the window																		
Not at all	184	7		9		6		7		45	6		8		7		8	
Occasionally	110	7		8		6		8		28	7		8		6		7	
Sometimes	58	7		8		6		7		9	6		8		6		6	
Often	26	8	**0.0274**	9	0.4471	7	**0.0080**	9	**0.0323**	6	8	0.2448	9.5	0.2985	6.5	0.2859	7	0.2140
Almost always	8	7.5		8.5		7		7		2	9		9.5		7.5		8.5	

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Difficulty getting by financially																		
No	305	7	**0.0790**	8	0.8026	6	**0.1115**	7	**0.1826**	67	7	0.7021	8	**0.0426**	7	**0.1647**	7	**0.0362**
Yes	33	7		8		7		8		5	8		9		8		9	
Contact with relatives & friends																		
Almost daily	332	7	0.6514	8	0.6777	6	0.7219	7	0.6953	74	6		8		7		7	
At least once a week	45	7		9		7		7		16	7.5	0.6996	8	0.4041	7	0.6884	7.5	0.9914
1-3 times a week	5	6		8		6		7		0								
<1 at month	2	6.5		8		6.5		7.5		0								
Rarely or never	1	9		9		9		10		0								
Does not wish to answer	1	5		6		5		7		0								
Previous miscarriages																		
No	325	7	0.6327	8	**0.0712**	6	0.4725	7	0.2310	70	7	0.7487	8	0.2329	7	0.2907	7	0.2418
Yes	72	7		9		7		8		20	7		8.5		7		8	
Indoor sources																		
WiFi																		
No	27	8	**0.1795**	9	0.3081	6.5	0.8535	7	0.9298	9	8	**0.0447**	9	**0.1497**	5.5	**0.1445**	6.5	**0.0945**
Yes	360	7		8		6		7		81	6		8		7		8	
DECT																		
No	105	7	0.7671	9	**0.1828**	7	0.3922	8	**0.1726**	22	6	0.8409	8.5	0.7162	7	0.2507	8	0.5838
Yes	274	7		8		6		7		66	7		8		7		7	

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Number of electronic devices used regularly at home																		
0-17	354	7	0.3555	8	0.2266	6	0.9848	7	0.8089	79	7	**0.0854**	8	**0.1348**	7	**0.0398**	8	**0.0249**
>=18	33	7		9		7		8		11	4		8		5		6	
Regular use of electronic devices at home																		
0-9	366	7	0.3555	8	0.2266	6	0.9848			84	6.5	0.3576	8	**0.1354**	7	0.3379	7	0.3617
10-12	21	7		9		7				6	7.5		9		7.5		8	
Outdoor sources																		
MP antenna <300 m																		
No	333	7	**0.2448**	8	0.6916	6	**0.1134**	7	**0.2435**	76	7	0.8742	8	0.6910	7	0.4943	8	0.5602
Yes	54	7		8		7		8		14	6.5		8.5		6		7	
MP antenna <600 m																		
No	140	7	0.8937	8	0.5958	6.5	0.6308	7	0.5107	34	6	**0.2049**	8	0.7278	7	0.5904	8	**0.1904**
Yes	247	7		8		6		8		56	7		8		6		7	
DVB-T (television) antenna ≤ 600 m																		
None	325	7	**0.0174**	8	0.2697	7	**0.0109**	8	**0.0225**	77	7	0.6203	8	0.3520	7	0.9409	7	0.6126
≥1	60	7		8		5		7		13	6		8		6.5		8	
Very high voltage (132 kV) power lines within 150 meters																		
None	381	7	0.4363	8	0.3471	6	**0.1477**	7	0.5775	90								
Some	3	7		9		7		7		0								

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
High (30 kV) and medium (13.2 kV) voltage power lines within 150 meters																		
Overhead																		
None	321	7	0.3973	8	0.9802	6	0.8728	7	0.7559	75	6	0.6246	8	0.3622	6	0.2999	7.5	0.8720
Some	63	7		8		6		8		15	8		9		7		7	
Underground																		
None	144	7	0.6728	8	0.7423	6	0.8423	7	0.9009	30	7	0.5780	8	0.9652	7	**0.1664**	8	**0.1891**
Some	240	7		8		6		8		60	6		8		6		7	
Both over- and underground																		
None	202	7	0.3464	8	0.5621	7	0.5244	8	0.8586	50	7	0.4238	9	**0.1349**	6	0.8679	7	0.7891
Some	182	7		8		6		7		40	6.5		8		7		7.5	
Both over- and underground																		
0	202	7	**0.0990**	8	0.2807	7	**0.1020**	8	**0.0716**	50	7	0.2639	9	**0.1655**	6	0.4613	7	0.2173
1	157	7		8		6		7		33	6		8		6.5		7	
2	14	8		9		6.5		7		1	8		10		8		10	
3	6	9		9.5		9		8.5		4	8		8.5		7.5		9	
4	2	7.5		9		5.5		6.5		2	5		6		5		5.5	
5	3	5		9		7		9		0	-		-		-		-	
Transformer Stations (from 13.2 kV to 250-300 V) ≤50 meters																		
None	261	7	**0.0346**	8	0.2662	6	**0.0667**	7	0.3341	66	6	0.7213	8	0.9592	6	0.4024	7	0.9514
Any	125	7		8		7		8		24	7		8		7		7.5	

Supplementary Table 3 (continued)

Categorical variables	N (T_0)	Exp ELF T_0	p	Exp RF T_0	p	Effect ELF T_0	p	Effect RF T_0	p	N (T_1)	Exp ELF T_1	p	Exp RF T_1	p	Effect ELF T_1	p	Effect RF T_1	p
Transformer Stations (from 13.2 kV to 250-300 V) ≤50 meters																		
0	261	7		8		6		7		66	6		8		6		7	
1	119	7	**0.0707**	8	**0.1740**	7	**0.0847**	8	0.2767	23	7	0.4484	8	0.4935	7	**0.1626**	8	0.3887
2	6	6		6.5		4.5		6		1	4		6		3		5	
Numerical variables		β	p	β	p	β	p	β	p		β	p	β	p	β	p	β	p
Poor dietary habits of the children		0.01	0.815	0.00	0.963	0.00	0.939	0.00	0.962		0.00	0.998	0.04	0.587	-0.04	0.478	-0.1	**0.103**
Negative feelings of the mother		0.04	0.243	0.04	0.214	0.04	0.253	0.09	**0.015**		0.01	0.879	0.02	0.834	0.04	0.585	0.10	0.239
Mental health of the mother (General mental health, GHQ-12)		0.06	**0.024**	0.06	**0.012**	0.03	0.291	0.05	**0.101**		0.04	0.597	0.00	0.949	0.08	0.247	-0.02	0.829
Mental health of the mother (Global Severity Index, SCL-90-R)		0.03	**0.024**	0.01	0.441	0.03	**0.050**	0.03	**0.026**		0.05	**0.079**	0.02	0.464	0.01	0.661	0.01	0.657
Intelligence of the mother (WAIS)		0.02	0.595	0.03	0.362	-0.04	0.285	-0.01	0.714		-0.25	**0.009**	-0.19	**0.043**	0.04	0.672	-0.07	0.495

Exp: exposure; T_0: Time of first questionnaire, before knowing the exposure levels at home; T_1: Time of second questionnaire, after knowing the exposure levels at home; There were no FM radio antennas within 600 meters of any of the homes; p values below 0.2 are represented in bold; GHQ-12: General Health Questionnaire; SCL-90-R: Symptom Checklist 90 Revised; WAIS: Wechsler Adult Intelligence Scale-Third edition

Supplementary Table 4

Sensitivity analysis

Variables	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
	B (95% CI)							
Social class								
Non-manual			Reference		Reference	Reference		
Manual			**0.46 (0.04 to 0.88)**		**1.11 (0.17 to 2.04)**	**1.05 (0.18 to 1.92)**		
Type of area								
Rural/Semi urban	Reference	Reference						
Urban	**0.53 (0.16 to 0.91)**	**0.40 (0.08 to 0.72)**						
Smoking								
No							Reference	
Yes							**-1.42 (-2.75 to -0.08)**	
MP antenna≤300m								
No								
Yes								
Sociocultural groups								
0 groups	Reference							
1 group	-0.08 (-0.50 to 0.36)							
> 1 group	**0.54 (0.07 to 1.01)**							
Groups related to environment or politics								
None			Reference					
≥ 1 group			**0.76 (0.07 to 1.45)**					

Supplementary Table 4 (continued)

Variables	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
					B (95% CI)			
Good neighborhood to live in								
Totally agree	Reference							
Fairly agree	**0.49 (0.10 to 0.88)**							
Neither agree nor disagree	0.47 (-0.23 to 1.18)							
Somewhat disagree	0.40 (-1.74 to 2.54)							
Totally disagree	-							
Do not want to answer	1.78 (-1.81 to 5.36)							
Bothered about air pollution when opening a window								
Not at all	Reference		Reference	Reference				
Occasionally	0.11 (-0.32 to 0.55)		0.02 (-0.45 to 0.48)	0.08 (-0.37 to 0.53)				
Sometimes	-0.08 (-0.63 to 0.47)		-0.29 (-0.88 to 0.30)	-0.08 (-0.66 to 0.51)				
Often	**1.10 (0.32 to 1.88)**		**1.17 (0.35 to 1.99)**	**1.26 (0.48 to 2.05)**				
Almost always	0.52 (-0.79 to 1.83)		0.80 (-0.60 to 2.21)	0.50 (-0.85 to 1.85)				
Age of the mother at birth of the child, years								
<25					-	-		-
25-29					Reference	Reference		Reference
30-34					-0.66 (-1.62 to 0.30)	-0.56 (-1.43 to 0.37)		**-1.05 (-2.04 to -0.07)**
≥35					**-1.88 (-3.23 to -0.52)**	**-1.88 (-3.15 to -0.62)**		**-1.45 (-2.84 to -0.06)**

Supplementary Table 4 (continued)

Variables	ELF exp T_0	RF exp T_0	ELF effect T_0	RF effect T_0	ELF exp T_1	RF exp T_1	ELF effect T_1	RF effect T_1
	B (95% CI)							
Number of calls of children by mobile phone								
<1 at week				Reference				
≥ 1 at week				**-0.64 (-1.28 to -0.00)**				
Electronic devices at home								
0-17							Reference	Reference
>18							**-1.60 (-2.81 to -0.39)**	**-2.10 (-3.42 to -0.78)**
WiFi at home								
No					Reference		**Reference**	
Yes					-1.40 (-2.82 to 0.01)**		**1.49 (0.15 to 2.83)**	
Difficulty getting by financially								
No								Reference
Yes								**2.33 (0.61 to 4.04)**
DVBT antenna ≤600 m								
None			Reference					
≥ 1			**-0.68 (-1.23 to -0.13)**					
LAT_LMT_A_S								
None	Reference							
≥ 1	**0.39 (0.02 to 0.77)**							
CT_50								
None	Reference							
≥ 1	**0.49 (0.09 to 0.88)**							
Mental health of the mother[a]		**0.05 (0.01 to 0.10)**						

[a] General mental score assessed by General Health Questionnaire (GHQ-12) ; *p=0.051; The models were adjusted for General mental score, Global Severity Index and intelligence of the mother when the p value in the bivariate analysis was below 0.2; CI: Confidence Interval

5. Eztabaida orokorra eta etorkizuneko lana

Egungo bizimoduan ezinbestekoak dira eremu elektromagnetikoak. Gainera, eremu horien erabilerak ematen dituen aukera eta abantailak gero eta handiagoak dira. EEI-EEMak naturan betidanik egon izan diren arren, iturri berriak sortzen joan gara, hala, esposizioa handituz. Osasun publikoaren arduretako bat ingurumen-osasuna da, zeinak ingurumeneko faktore arriskutsuen aurrean biztanleriaren osasuna zaindu, gaixotasunak prebenitu eta babesteko helburua duen. Ingurumen-arriskuek biztanleria osoari eragiten dietenez, berebiziko garrantzia du horiek ezagutu eta ekiditeak [1]. EEI-EEMek osasunean izan dezaketen eraginaren inguruan ez dago adostasun argirik zientzialarien artean, eta horrek herritarrak are eta gehiago nahasten ditu, eta gaiaren inguruan kezkaturik dauden herritarrek azalpenak eskatzen jarraitzen dute. Efektuen inguruan ikerketa ugari dauden arren [2], askori esposizioaren estimazio desegokia edo osatugabea egitea egotzi zaie [3]. Ikerketa epidemiologikoak gauzatzeko subjektuei atxikitzen zaien esposizio-kategoria (esposizio altua, ertaina edo baxua, esaterako) garrantzitsuagotzat jotzen da esposizio zehatza jakitea baino, klasifikazio desegokiak egiteak ekarri baititzake interpretazio akats nagusiak [3]. Ildo horretan, EEI-EEMen inguruko ikerketa epidemiologikoak egiteko ezinbestekoa izango den lehen pausuan, hau da, esposizioaren ezaugarritzean, sakontzea izan da tesi honen helburu nagusia, eta, hainbat metodologia erabiliz egin da ezaugarritze hori. Laburbilduz, ELF, bitarteko maiztasunen eta IMen esposizioa ezaugarritzeko neurketak egin ditugu umeek denbora gehien igarotzen duten lekuetan; etxe, eskola eta parkeetan hain zuzen ere. Horrez gain, IMak neurtzeko neurketa pertsonalak egin ditugu lagin txiki batean (50 pertsona) 3 egunetan zehar.

Emaitzei dagokienez, gure kohorteko umeek ELFen eremu magnetikoekiko duten esposizioa oso baxua dela aurkitu da (0,15 µT-etako batez besteko maximoa etxe batean) bai beste ikerketekin alderatuz, bai indarrean dauden araudi eta gomendioekin alderatuz ere [4,5]. Aldiz, ELFen eremu elektrikoaren esposizioa beste ikerketa batzuetan aurkitutakoaren antzekoa eta beste batzuetan aurkitutakoa baino altuagoa izan da gure kohortean (kuartilarte tartea 1-15 V/m barnealdean (etxe eta eskoletan) eta 0,3-1,1 V/m kanpoaldean (parke eta eskolako jolaslekuetan), maximoa 55,5 V/m izan zen parke batean) [6].

IMei dagokienez, neurketa puntualen mediana 29,73 µW/m^2 (logeletan) eta 200,10 µW/m^2 (eskoletako jolaslekuetan) artekoa izan zen. Esposizio pertsonalaren batez bestekoa eta mediana (169,19 and 52,13 µW/m^2), aurreko ikerketek adierazitako balioen tartean daude. Esposizio maila handiagoak aurkitu ziren barnealdean ELFen kasuan eta kanpoaldean IMen kasuan. Gure ikerketa-lagina umez osaturik dagoela eta, goranzko loturak (mugikorretik edo aparailu igorletik antenara doan seinalearen ondoriozko eremua) sorturiko esposizioa oso baxua izan zen. Aldiz, beste herrialde batzuetan baino esposizio handiagoa neurtu zen irrati-zerbitzura bideratutako uhinei zegokienez. Oro har, irrati eta telebista antenetatik igorritakoa eta telefonia mugikorretatik mugikorretara beraietara (edota hargailu den beste aparailuren batera) igorritakoa izan ziren IMen esposizio totalean eragin handiena izan zuten iturriak.

Horrez gain, egun ez dagoenez ikerketa epidemiologikoetara bideratutako esposizioa neurtzeko metodo estandarizaturik, hainbat neurketa mota egin ditugu, bai maiztasun baxuetarako bai irrati-maiztasunentzako. Hala, ELFei dagokienez umearen esposizio pertsonala estimatzeko askok etxean soilik egin izan dituzte neurketak [7–9], kontuan izanda haurrek eguneko ordu asko igarotzen dituztela etxean. Tesi honetan, etxeko neurketak egiteaz gain, denboraren arabera doitutako batez bestekoak (ingelesezko siglak: TWA, *Time-Weighted Average*) kalkulatu ziren, etxean, eskolan eta parkean neurtutako mailak umeak leku horietako bakoitzean igarotzen dituen orduen arabera estandarizatuta. Ikerketa honetako umeak hiru taldetan sailkatu genituen (esposizio baxua edo medianatik beherakoa; esposizio ertaina edo mediana eta 90 pertzentilaren artekoa; eta esposizio altua edo 90 pertzentila edo gorakoa) esposizioa kalkulatzeko erabilitako bi metodoetako bakoitzaren arabera (neurketak etxean soilik eta TWA). Bi metodologiekin lortutako esposizioaren klasifikazioen artean neurrizko komunztadura aurkitu genuen eremu magnetikoentzako (Cohen κappa = 0,58). Aldiz, eremu elektrikoarentzako funtsezko komunztadura ikusi genuen (Cohen κappa = 0,76). IMetan neurketa pertsonalekin lortutako esposizioaren klasifikazioa era ezberdinetan estimatutako TWAekin lortutakoarekin alderatu genuen, eta antzekotasun handiena etxe, eskola eta parkeetan jasotako neurriekin kalkulatutako TWAarekin zeukatela ikusi genuen, nahiz eta neurrizko komunztadura izan (IMeko esposizio totalerako Cohen κ = 0,46). Metodologien alderatze horrek, neurketa pertsonalak baino errazagoak diren metodologiak baliagarriak diren edo ez jakiten lagundu du. Gure ustez, baliagarria litzateke neurketa puntualetan oinarritutako esposizioaren klasifikazioa egitea umeen esposizio pertsonala estimatzeko.

Azkenik, proiektuko parte-hartzaileek EEI-EEMen inguruan nolako ardura zuten ikusita, tesi honetan sartzea erabaki zen pertzepzioaren inguruko ikerketa. Informazioa emateak esposizioaren pertzepzioan eragin baxua duela ikusi zen, baina kontuan izan behar da, neurketak etxean izan zituzten parte-hartzaileen artean soilik ebaluatu zela aldaketa. Beraz, baliteke garai desberdinetan galdera berei erantzun desberdina eman izana izatea aldaketa horren arrazoia, gure emaitzen interpretazioa kolokan jarriz. Horrez gain, garrantzitsua da pertzepzio altuagoa izatearekin erlazionatuta dauden aldagaiak ezagutzea, talde horien pertzepzioa behar baino handiagoa denetan eta arazo bihur daitekeenetan, haien pertzepzio mailak jaisteko, haientzako ekintzak egite aldera. Gizartea informatuta ez dagoenean eta zientzian oinarritutako datuak maneiatzen ez dituenean, ustez eta sinesmenez osatzen da pentsamendua. Erdibideko iritziez gain, muturreko bi jarrera ere bereizten dira. Batzuk konbentzituta egon daitezke EEI-EEMek efekturik ez dutela eta ikerketa gehiago egitea denbora eta dirua xahutzea litzatekeela. Besteek, ordea, konbentzimendu osoz uste dezakete EEI-EEMek efektu handiak dituztela, eta emaitza positiboak soilik adierazten dituzten dokumentuak hartzeko arriskua dute. Biak ala biak jarrera arriskutsuak izan daitezke, eta zientziak egiten duen lana gutxiestera eraman dezakete. Bestalde, azkenengoek, hainbat gaixotasun ez-espezifiko garatzeko arriskua dute, eta horien garatzea hautemandako esposizioarekin erlazionatuta dago, benetan dagoen esposizioarekin egon beharrean [10].

Etorkizuneko lana

Egindako lanaren jarraipena eskatzen du tesi honek, eta aukera emango du metodologia ezberdinak erabiliz estimatutako esposizio mailak konparatzeko kohortearen ondorengo jarraipenetan lortutako osasun emaitzekin, batez ere neurogarapenari eta loaren kalitateari dagokionez. Bestalde, badira hainbat gai tesi honetan gauzatu edota kontuan hartu ez direnak.

Modelo geoespazialak

IMen inguruan, baliagarri izan daitezke lagin handi baten esposizio mailak ezagutzeko. Ikerketa honetan, IMak neurtzeko Frei et al.-en, (2010) metodologia [11] jarraitu zen etxeetan, hein batean, ondoren NISMap modeloaren [12] balidazioa egiteko. Momentuz, ezin izan da burutu, telefonia mugikorren antenen inguruko datu teknikoak lortzeko izan diren zailtasunengatik. Modelo hauek, behin balioetsita, guk neurketa puntualen bidez proposatutako lanak baino gehiago erraztuko lukete landa-lana, eta kanpo zein barnealderako arrakastaz erabili dira [13,14]. Dena dela, modelo horiek ez dute kontuan hartzen erabilera pertsonalari dagokien esposizioa, eta telefonia mugikor eta irrati- eta telebista-antenei dagokien esposizioa soilik modelizatzen dute. Gainera, ELF eta bitarteko maiztasunentzako modelo egokirik ez da garatu oraindik [15].

Bestalde, herrien erradiazio-mapak izatea baliagarria izango litzateke ingurumen eta osasun publikoaren kudeaketara bideratutako ekintzetarako.

Eremu hurbileko esposizioa

Sarreran azaldu bezala, iturri baten inguruan eremu hurbila eta eremu urruna desberdintzen dira. Uhin luzeraren hirukoitza den distantziara (metrotan) hasten da eremu urruna, gutxi gora behera. ELF eta bitarteko maiztasunen uhinak direnean, eremu hurbilean aurkitzen gara normalean, baina IMak direnean, iturriaren araberakoa izango da. Esaterako, telefonia mugikorreko UMTS antenaren eremu hurbila 43 cm-ra edo amaituko da, eta biztanleria orokorra ez denez antena horretatik hain hurbil egoten, esposizioa eremu urrunean emango da. Aldiz, UMTS teknologia (1920 MHz inguru) darabilen mugikor baten eremu hurbilak mugikorretik 47 cm-ra arteko distantzia edo hartzen du. Mugikorra, normalean, gorputzetik gertu erabiltzen denez gero, mugikorraren erabiltzaileak eremu hurbilean jasoko du esposizioa. Tesi honetan, ELFen eremu hurbilean eta IMen eremu urrunean jasotzen den esposizioa eduki da kontuan. Eremu hurbilean ematen den IMen esposizioa neurtzeko, energia-xurgatzearen tasa espezifikoa (ingeleseko siglak: SAR, *Specific Absortion Rate*) erabili behar da. Premiazkoa litzateke ondorengo ikerketek era integratu batean estimatzea eremu hurbileko zein urruneko esposizioa. Bestalde, tesi honetan esposizioa neurtu dugu, eta ez dosia. Masa biologiko batek denbora jakin batean xurga dezakeen energia elektromagnetikoa zehazten du SARak. ELFei dagokienez, barneko eremu elektrikoaren intentsitatea erabiltzen da jasotzen den dosia kalkulatzeko [16].

Iturri eta erabilera berriak

Teknologia oso azkar ari da garatzen eta EEI-EEMen inguruko ikerlariek prest egon beharko dute etengabeko aldaketei aurre egiteko. Orain arte erabili ez diren maiztasunak erabiltzeari ekingo zaio eta erabilera-ohiturak ere aldatu egingo dira. Hala, esaterako, haurdunaldian amak mugikorra erabiltzea umeak 7 eta 11 urte zituenean arazo emozionalak eta portaera-arazoak edukitzearekin erlazionatu zuen Danimarkako DNBC kohorteak. Era berean, umeak berak mugikorra erabiltzea ere erlazionatu zen aipatutako arazoekin [17,18]. Gaur egun, aldiz, horrelako ikerketa prospektiboak egitea ezinezkoa da, biztanleriaren gehiengoak erabiltzen baitu mugikorra eta, dagoeneko ez dago klase sozial bati estuki lotua. Gainera, mugikorra, lehen, hitz egiteko erabiltzen bazen ere nagusiki, egun, bestelako erabilerak ere baditu; batez ere, mezuen bidez komunikatzea eta hainbat aplikazio erabiltzea [19]. Hala, gorputzeko SAR balioak eta esposizioa gehien jasaten duten gorputzeko atalak beste batzuk izan daitezke.

Bitarteko maiztasunak

Tesi honetan, gero eta gehiago erabiltzen ari diren bitarteko maiztasunekiko esposizioa neurtu da. Esposizio mailak antzekoak izan ziren kanpo zein barnealdeetan. Aurretik oso ikerketa gutxi zegoen mota horretako esposizioa neurtu zuena [6], eta, beraz, nahiz eta balio baxuak izan (leku ezberdinetarako medianak 0,019 eta 0,023 µT artekoak eta 0,216 eta 7,646 V/m artekoak izan ziren, hurrenez hurren, eremu magnetiko eta elektrikorako), ezin ditugu gure emaitzak konparatu.

Esposizioaren ebaluazio integrala beharrezkoa da, bai dauden esposizio mailei buruzko ezagutza eskuratzeko, bai etorkizuneko ikerketa epidemiologikoak garatzeko. Dagoen datu falta aintzat hartuta, MOEk eta SCENIHRek lehentasunezkotzat jo dute bitarteko maiztasunen eremu magnetiko zein elektrikoarekiko umeek duten esposizioa ezaugarritzea [20–23].

Eremu elektrikoa

ELF eta bitarteko maiztasunez ari garela, iturriaren eremu hurbilean gaudenez, eremu magnetikoa eta elektrikoa bereizita neurtu behar dira. Ikerketa gehienek eremu magnetikoa neurtu dute, umeek leuzemia izateko arriskuarekin erlazionatu zenetik [24–26]. Gainera, eremu elektrikoak magnetikoak baino zailagoak dira neurtzen, aldakortasun handiagoa dutelako denboran zehar, eta edozein material eroalek eremuak asaldatzen dituelako [6]. Tesi honek duen balio gehigarrietako bat umeek eremu elektrikoekiko duten esposizioa neurtzen duela da.

Umeak

Tesi hau umeetan zentratu da. Eztabaidagai dago, oraindik, umeak EEI-EEMekiko helduak baino sentiberagoak ote diren [3,27–29]. Argi dagoena da, umeek, bizitzan zehar, esposizio handiagoa eta luzeagoa izango dutela, gaur eguneko helduekin alderatuz. Gainera, umeen nerbio-sistema oraindik garatzen ari da eta haien buruak helduenak baino txikiagoak direnez, bolumeneko xurgatzen den energia helduena baino handiagoa izan liteke [28,30]. Dena den, ezaugarri dielektrikoak ezberdinak izan daitezke ume eta helduen artean, eta horrek SAR indizean eragin egingo luke [29]. Hasiera batean, SARa kalkulatzeko erabilitako modeloak helduen buruetan oinarrituta zeuden arren, hainbat hurbilpen egin dira umeen SARa estimatzeko. Lehenbiziko umeen modeloak, helduenaren berdina ziren, tamaina txikiagoan eginak. Haatik, umeen burua ezin da helduen buru txiki gisa definitu. Umeen buruak helduen buruaren tamaina hartzen du umeak 6 eta 14 urte bitartean dituenean [30]. Wiart et al. ek (2008), umeen ezaugarrietara egokitzeko, erresonantzia magnetikoko irudien bitartez modelizatu zituzten umeen buruak, SARa kalkulatzeko [30].

Ezaugarri fisiko-kimikoez gain, umeei eragingo dieten esposizio determinatzaileak eta gehien eragiten duten iturriak aldatzen joan daitezke.

Tesi honek ateak irekita uzten ditu, ikerketa prospektiboa den heinean 8 urtetan neurtutako esposizioa hurrengo urteetan izango duten garapenarekin erlazionatzeko. Bestalde, baliagarria izango da haurrak hazi ahala EEI-EEMen iturrien erabileran egingo dituzten aldaketak jasotzeko ere. Hala, gure kasuan, IMei dagokienez umeen gehiengoak ez zuen mugikorrik erabiltzen 8 urterekin eta kohortean egingo diren hurrengo jarraipenetan hori aldatu egingo dela uste da.

Beste zalantza batzuk

Argitu gabe dago, oraindik, esposizioaren ezaugarritzeari dagozkion beste hainbat kontu. Efekturik baldin bada, eta mekanismo biologikoa ezagutzen ez den bitartean, ikerketa zailtzen du esposizioaren zein aspektuk duen garrantzia ez jakiteak. Esaterako, maiztasun jakin batzuek beste batzuek baino gehiago eragin dezaketen ikertu behar da oraindik. Lurraren eremu magnetikoa esaterako, guk neurturiko balioak baino 1.200 aldiz handiagoa da gutxienez (25 eta 65 µT artekoa), baina korrontea estatikoa da, eta guk neurturikoa, berriz, alternoa. Bestalde, ICNIRPk egindako gomendioak esposizio akutuan oinarritu dira [31] eta munduko estatu askotako legeek gomendio horri jarraituz ezarri dituzte esposizio mugak. Hala ere, ez dakigu maila baxuko esposizio kronikoak zelan eragin dezakeen, eta, hori argitzeko, ikerketa prospektiboen beharra dago. Jakina denez, kausalitatea frogatutzat emateko Bradford Hillen postulatuei jarraitzen zaie; asoziazioaren indarra; espezifikotasuna, biologikoki onargarria den mekanismoa egotea; beste ikerketa batzuekin bat etortzea; denbora sekuentziak errespetatzea eta dosi-erantzun gradientea gertatzea. Laborategiko ikerketen eta ikerketa epidemiologikoen arteko koherentzia eta analogia ere aipatu zituen Hillek [32]. Jarraibide malgu gisa aurkeztu zituen arren, egun oraindik oso erabiliak dira, epidemiologia arloan, kausalitatea frogatutzat emateko. Dena den, irizpide horien interpretazioa aldatuz joan da [33]. EEI-EEMen eremuan asko dago egiteke, irizpide horietariko bakoitzari erantzuna emateko.

Pertzepzioa

Garrantzitsua da erakunde publikoek biztanleria informatuta edukitzea, eguneratutako datuetan oinarritutako informazioa helaraziz. Informazio hori nola eman behar den ikertzeke dago oraindik, informazioa emateko moduak sinesgarritasunean eta ulergarritasunean eragin bailezake, lortu nahi diren kontrako emaitzak lortuz. Bestalde, erakunde ezberdinek iritzi bateratua ez edukitzeak herritarrak gero eta gehiago nahasten ditu, eta beraz, erantzun bateratua funtsezkoa da. Azkenik, pertzepzio mailak behar baino gehiago ez igotzeko saiakerak soilik egin litezke EEI-EEMen inguruko ezagutzaren aurrerapenarekin batera.

Bizitzan ez dago beldurtzeko moduko ezer, ulertzeko baizik. Orain da momentua gehiago ulertzeko, beldur gutxiago izan dezagun- Marie Skłodowska-Curie

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6. Ondorioak

- Kanpo-inguruneko EEI-EEMen iturriei dagokienez, 8 urteko jarraipenean ikerketan parte hartu zutenen etxeen erdiak baino gehiagok zuen goi tentsioko (30 kV-12 kV) lurrazpiko linearen bat 150 metrotara, baina erdiak baino gutxiagok zuen goi tentsioko aireko linearen bat distantzia horretan. Oso etxe gutxik (hiruk) zuen oso goiko tentsiodun linea (132 kV) 150 metrotara. Etxeen herenak zuen azpiestazioren bat 50 metrotara (13,2 kV-etik 250-300V-ra eraldatzeko). Eskolen erdiak baino gutxiagok zuen oso goiko tentsiodun linea edo goi tentsioko aireko linearen bat 200 metrora. Aldiz, eskolen bi herenek zuten aire eta lurrazpiko konbinaziodun linearen bat 200 metrora eta azpiestazioren bat 100 metrora. Iturrien ehunekoa, parkeen inguruan, eskoletakoaren antzekoa zen, baina parkeen gehiengoak, gainera, lurrazpiko goi tentsioko lineak zituen 200 metrora. Garraiorako erabiltzen den oso goiko tentsiodun linearik (200-300 kV) ez zegoen gure ikerketa-eremuan. Irrati-maiztasunei dagokienez, etxeen hamarren batek soilik zuen telefonia mugikorreko antenaren bat 300 metrora, baina bi herenek zuen baten bat 600 metrora. Seirenak baino gutxiagok zuen telebistako seinalea igortzen duen antenaren bat 600 metrora. Irratiko seinalea igortzen zuen antenarik ez zegoen etxeetatik gertu (600 metro baino gutxiagora). Ez zegoen alderik neurtutako etxeen eta neurtu gabekoen artean kanpoaldeko iturriei dagokienez. Gainera, CTE/23/2002 aginduan arautzen denez haur-eskoletatik, derrigorrezko hezkuntza zentroetatik, osasun zentroetatik, ospitaletatik, parke publikoetatik, zahar-egoitzetatik edo eguneko zentroetatik 100 m baino gutxiagora dauden estazio erradioelektrikoen operadoreak esposizioaren gutxitzea arrazoitzera behartuta daude, eta gure ikerketa-eremuan, irizpide hori betetzen zuten espazioak bazeuden ala ez ikertu zen. Bi inguru sentikorrek, hots, ospitale batek eta parke batek zuten, soilik, telefonia mugikorreko antenaren bat 100 metroko distantzian eta, beraz, esposizioa ahalik eta gehien gutxitzeko saiakerak egiteko justifikazioa aurkeztu beharko lukete.

  Barnealdeko iturriei dagokienez, etxeen gehiengoak zuen WiFia eta bi herenek hari gabeko telefonoa. Orokorrean, umeek ez zuten euren telefono mugikorrik eta hamarren batek baino gutxiagok, soilik, erabiltzen zuen edozein mugikor astean behin gutxienez.

- Umearen esposizioan ekarpen handiena egiten duten lekuak eremu eta iturriaren araberakoak dira. Era horretan, ELFei dagokien esposizioa esanguratsuki handiagoa izan zen barnealdean, hots, etxe eta eskoletan kanpoaldean baino, batez ere eremu elektrikoaren kasuan. Esposizioaren mediana, maiztasun eta leku ezberdinetarako ELF-MFen kasuan, 0,011 eta 0,023 µT artekoa izan zen, eta ELF-EFen kasuan, 0,216 eta 7,886 V/m artekoa.

  IMei dagokienez, ordea, alderantzizkoa gertatzen da. Hau da, IM totalaren esposizio mailarik altuenak kanpoaldean gertatzen dira. Iturriaren arabera aztertuz, irrati, telebista eta beheranzko loturaren (telefonia mugikorreko antenatik telefono mugikorrera doan seinaleak sortutakoa) ondoriozko esposizioa altuagoa izan zen kanpoaldean barnealdean baino. Goranzko loturak (mugikorretik telefonia mugikorreko antenara doan seinaleak sortutakoa) sortutako esposizioa antzekoa izan zen kanpo zein barnealdean, eta umeen logelak eta eskoletako jolaslekuak izan ziren iturri honen mailarik baxuenak zituztenak. WiFi eta hari gabeko telefonoaren neurketak, aitzitik, barnealdean izan ziren nabarmenagoak. Are gehiago, hari gabeko telefonoa, etxeetako egongeletan soilik nabaritu zen (bataz bestekoa/mediana: 2,43/0,08 µW/m^2). WiFiak sorturiko esposizioa handiagoa izan zen etxeetan (batez ere, egongeletan; bataz bestekoa/mediana 12,7/2,92 µW/m^2) eskolako ikasgeletan baino (bataz bestekoa/mediana 2,33±1,29/1,74 µW/m^2).

- Egunean zehar ume bakoitzak dituen ELF eta IM mailak hainbat eratan kalkulatu ziren. Kohorte honetako umeek 16 ordu etxean, 5,5 ordu ikasgeletan, 1 ordu eskolako jolaslekuan eta 1,5 ordu parkeetan pasatzen zituzten, beti ere parte-hartzaile guztien mediana kontuan hartuz. Ordu kopuru horiek erabiliz kalkulatutako TWAn bataz bestekoa, mediana eta 90 pertzentila 0,018, 0,015 eta 0,025 µT izan zen, hurrenez hurren, ELF-MFen kasuan eta 7,56, 6,93 eta 13,30 V/m ELF-EFen kasuan.

IMen kasuan 50 pertsonako lagin batean egindako neurketa pertsonalen bidez lortutako IM esposizio totalaren bataz bestekoa eta mediana 169,19 eta 50,14 µW/m^2 izan ziren, hurrenez hurren. Gainera, hainbat eratara kalkulatu genuen umearen TWA, baina beti neurketa puntualetan oinarrituta. Bataz bestekoa 115,08 (umearen logela) eta 500,27 µW/m^2 (gurasoek esandako ordu kopuruetatik doituriko TWAk) arteko tartean ibili zen eta mediana 25,46 (umearen logela) eta 123,21 µW/m^2 (gurasoek esandako ordu kopuruen medianatik doitutako TWAk) artean.

- Tesi honetan ezaugarritu dira lehenengo aldiz bitarteko maiztasunak umeek denbora gehien igarotzen duten inguruneetan. 12 Hz eta 100 kHz arteko maiztasuneko eremu magnetikoaren batez bestekoa, neurtutako lekuaren arabera, 0,021 eta 0,027 µT artekoa izan zen, eta mediana, 0,020 eta 0,023 µT artekoa. Bitarteko maiztasunen eremu elektrikoaren balioak asko aldatu ziren neurtutako maiztasun tartearen arabera. Era horretan, 12 Hz eta 1 kHz artean, 1,66 eta 10,11 V/m artekoa izan zen bataz bestekoaren tartea leku ezberdinetarako, eta, 1,2 kHz eta 100 kHz artean, 0,28 eta 0,45 V/m artekoa. Mediana, aldiz, 1,00 eta 7,89 V/m artekoa izan zen 12 Hz eta 1 kHz-ko maiztasun tartean, eta 0,22 eta 0,39 V/m artekoa, 1,2 kHz eta 100 kHz tartean. Ez zen aurkitu bitarteko maiztasunen tarteko esposizioari ekarpen nabarmenik egiten zion maiztasunik. Maiztasun-tarte horren mailak ezaugarritzen dituzten ikerketa gehiago behar dira, maiztasun horiek erabiliko dituzten iturri berriak agertzen diren heinean.

- ELFen eremu magnetiko eta elektrikoaren arteko korrelazioa baxua zela aurkitu zen; maiztasun-tarte eta leku ezberdinetarako 0,044 eta 0,357 artekoa izan zen. Bitarteko maiztasunen eremu magnetiko eta elektrikoaren arteko korrelazioa, aldiz, neurrizkoa edo altua izan zen, 0,285etik 0,752rako Spearman korrelazio esanguratsuak lorturik. Beraz, ELFen esposizio maila jakiteko bi eremuak (magnetikoa eta elektrikoa) neurtzea ezinbestekoa dela jakina bazen ere, orain badakigu klasifikazio egoki bat lortzeko ere biak neurtu behar direla. Bitarteko maiztasunei dagokienez, aldiz, 1.2kHz eta 100 kHz arteko tartean eremuetako bat neurtuz eta lortutako esposizioaren klasifikazio bat eginez, beste eremuaren sailkapena aurresan ahalko da errore handirik gabe. Dena den, erlazio on hori ulertzeko, kontuan izan behar da, ikerketa honetan aldakortasun gutxi ikusi zela.

- IMei dagokienez, esposizio totalean ekarpen handiena egin zuten iturriak, bai neurketa puntualetan bai neurketa pertsonaletan, irrati antenak, telefoniako beheranzko loturak (telefonia mugikorreko antenatik telefono mugikorrera doan seinalea) eta telebista-antenak (seinalea igortzen dutenak) izan ziren, hurrenkera horretan. Aitzitik, goranzko loturak (telefonia mugikorretik telefonia mugikorraren antenara doan seinalea) IM esposizio totalera egindako ekarpena aintzat ez hartzeko modukoa izan zen (% 4,5ekoa soilik). WiFi eta hari gabeko telefonoak, biak batera, esposizio totalaren % 3 baino gutxiago eman zuten. Mugikorraren erabilerari zor zaion goranzko loturaren ekarpena zertxobait handiagoa (% 6 handiagoa) izan zen neurketa pertsonaletan, neurketa puntualekin alderatuz, baina bietan izan zen baxua. Hala, neurketa pertsonaletan, goranzko loturak egindako ekarpena % 4,5 (batez bestekoa) eta % 9,5 (mediana) izan zen. Ekarpen-patroiak berdintsuak izan ziren neurtutako leku guztietan.

- ELF eta IM maiztasun tarteak neurtzeko erabilitako metodologia ezberdinekin lortutako esposizioaren klasifikazioak alderatu ziren. Etxean neurtutako ELF-MF eta eskola, etxe eta parkeetan egindako neurketa puntualekin kalkulatutako TWA bidez egindako klasifikazioen artean neurrizko komunztadura lortu zen eta komunztadura hobea, funtsezkoa, lortu zen ELF-EFentzako. IMei dagokienez neurketa pertsonalekin lortutako esposizioaren klasifikazioa era ezberdinetan estimatutako TWAekin lortutakoarekin alderatu zen eta antzekotasun handiena etxe, eskola eta parkeetan lorturiko neurriekin kalkulatutako TWAarekin ikusi zen, nahiz eta neurrizko komunztadura izan.

- Ikertu ziren ELFen aldagai azaltzaile izan litezkeen guztietatik, etxearen eraikitze urtea, eskoletako arbel digitalaren erabilera eta parkeen kasuan 200 metro edo gutxiagoko distantzian aireko tentsio linea (30-13,2 kV) izatea izan ziren ELFen eremu magnetikoaren balio zertxobait altuagoak azaldu zituztenak.

- Haurdunaldian zehar, amek, emandako 16 ingurumen kutsatzaileetatik, heren batek IM antenekiko eta goi tentsioko lineekiko gertutasuna hautatu zuten euren bizitokietako 5 ingurumen arazo garrantzitsuenetariko gisa, bosgarren eta seigarren tokian kokatuz, hurrenez hurren. Bestalde, umeek 8 urte zituztenean euren amek oso pertzepzio altuak (10eko puntuaziotik 7-8 arteko puntuazioak) adierazi zituzten, bai esposizio pertzepzioari zegokionez bai osasunerako arriskuari zegokionez.

- Umeek 8 urte zituztenean, euren etxeetako neurketetan lortutako emaitzen inguruko informazioa emateak amen esposizio pertzepzioan oso eragin gutxi eduki zuen, hots 0,7 puntutan jeitsi zen. Gainera, osasunaren arriskuaren inguruko pertzepzioan ez zuen inolako eraginik izan. Dena den, informazioa jaso aurretik eta ondoren emandako erantzunen artean korrelazio baxua aurkitu zen.

- Klase sozial eskulangilea izateak, hiri ingurunean bizitzeak eta gazteagoa izateak pertzepzio maila altuagoak azaltzen zituzten aldagaiak izan ziren, galdetutako pertzepzio batean baino gehiagotan. Halaber, auzo atsegin batean bizitzearen sentsazioa edukitzea, aire kutsaduragatik leihoa irekitzeak gehiago molestatzeak eta etxean aparailu elektriko gutxiago izateak ere pertzepzio maila altuagoak izatearekin erlazionatu ziren.

- Proiektuko parte-hartzaileen amek adierazi zuten erakunde publikoetatik EEI-EEMen esposizio mailen eta euren efektuen inguruan batere informaziorik ez edo informazio gutxi jasotzen zutela, eta informazio hori jasotzea ezinbestekoa dela aditzera eman zuten. Osasunaren politika kudeatzen duten erakundeek bi esparrutan egin beharko lukete lan etorkizunean; batetik, esposizio eta efektu posibleen inguruan argitzeke dauden gaiak ikertzea, eta, bestetik, jendea informatuta edukitzea. Ikergai dago oraindik eman beharreko informazioa nola eman behar den, pertzepzioaren handitzea ekidin behar baita beharrezkoa ez denean.

SCIENTIFIC PUBLICATIONS

1. **Gallastegi, M.**, Guxens, M., Jiménez-Zabala, A., Calvente, I., Fernández, M., Birks, L., Struchen, B., Vrijheid, M., Estarlich, M., Fernández, M. F., Torrent, M., Ballester, F., Aurrekoetxea, J. J., Ibarluzea, J., Guerra, D., González, J., Röösli, M. and Santa-Marina, L. Characterisation of exposure to non-ionising electromagnetic fields in the Spanish INMA birth cohort: study protocol. *BMC public health*, 2016;16(1):16. doi: 10.1186/s12889-016-2825-3..

2. **Gallastegi, M**., Jiménez-Zabala, A., Santa-Marina, L., Aurrekoetxea, J. J., Ayerdi, M., Ibarluzea, J., Kromhout, H., González, J. and Huss, A. Exposure to extremely low and intermediate-frequency magnetic and electric fields among children from the INMA-Gipuzkoa cohort. *Environmental Research.* 2017;157:190–197. doi: 10.1016/j.envres.2017.05.027.

3. **Gallastegi, M**., Tamayo-uria, I., Jiménez, A., Aurrekoetxea, J. and Santa-marina, L. Antenas de telefonía móvil : emplazamiento y proximidad a espacios sensibles en la zona de estudio INMA-Gipuzkoa; [Mobile telephony antennas : localization and proximity to sensitive areas in the INMA-Gipuzkoa study]. *Revista de Salud ambiental* 2014;14(2):98–106.

4. **Gallastegi, M.**, Jiménez-zabala, A., Santa-marina, L., Aurrekoetxea, J. J. and Ayerdi, M. Percepción del riesgo a campos electromagnéticos de radiofrecuencia en la cohorte INMA-Gipuzkoa; Perception of the risk to electromagnetic RF fields in INMA-Gipuzkoa cohort. *Revista de Salud ambiental* 2016;16(2):118–126.

5. **Gallastegi, M**. Jiménez-Zabala A, Aurrekoetxea JJ, Santa-marina L and Ibarluzea J. Erradiazio ezionizatzaileko eremu elektromagnetikoen eraginak osasunean : ezagutza-egoeraz egun dakiguna, [Health effects of non-ionizing electromagnetic fields: current state of knowledge]. *Ekaia* 2016; 30:105–123. doi: 10.1387/ekaia.16148.

6. **Gallastegi M**, Huss A, Santa-Marina L, Aurrekoetxea JJ, Guxens M, Birks LE, Ibarluzea J, Guerra D, Roosli M, Jiménez-Zabala A. Children’s exposure assessment of radiofrequency fields: comparison between spot and personal measurements, Under revision in *Environment International*

7. **Gallastegi M**., Jimenez-Zabala A., Molinuevo A., Santa-Marina L, Ibarluzea J., Aurrekoetxea JJ. Exposure and health risks perception of extremely low frequency and radiofrequency fields and the effect of providing information. *To be submitted*

SCIENTIFIC CONFERENCES

14th INMA (Environment and childhood project) scientific conferences.

Granada (Spain)

November 20-21, 2017

- Poster: Children's exposure assessment of radiofrequency fields by spot and personal measurements
- Poster: Exposure and health risks perception of extremely low frequencies and radiofrequencies

XIV Congreso Español y IV Congreso Iberoamericano de Salud Ambiental y I Jornada de la Asociación Española de Aerobiología

Zaragoza (Spain)

June 21-23, 2017.

- Oral communication: "Exposición a campos electromagnéticos de radiofrecuencia de los niños de la cohorte INMA-Gipuzkoa"
- Oral communication: "Percepción de la exposición y riesgos para la salud de frecuencias extremadamente bajas y radiofrecuencias en la cohorte INMA-Gipuzkoa" **Best presentation award**

28th Conference of the International Society for Environmental Epidemiology

Rome (Italy)

September 1-4, 2016

- Poster: Risk perception of radiofrequency electromagnetic fields among INMA-Gipuzkoa birth cohort participants
- Poster: Characterisation of exposure to non-ionising electromagnetic fields in primary schools belonging to the study area of INMA-Gipuzkoa birth cohort

13th INMA (Environment and childhood project) scientific conferences.

Sabadell (Spain)

27-28 October, 2016

- Oral communication: Characterization of exposure to Non-Ionizing Electromagnetic Fields in primary schools belonging to the study area of INMA-Gipuzkoa birth cohort

- Poster: Risk perception of Radiofrequency electromagnetic fields among INMA-Gipuzkoa birth cohort participants

XIII Congreso Español de Salud Ambiental

Cartagena (Spain)

June 24-26, 2015

- Oral communication: "Caracterización de la exposición a campos electromagnéticos CEM-RNI (0Hz–6GHz) de radiación no ionizante en los niños de la cohorte INMA-Gipuzkoa: resultados preliminares."
- Poster: "Plan de actuación para el establecimiento de las áreas de influencia y medida de radiofrecuencia en espacios sensibles en Gipuzkoa: resultados preliminares."

12th INMA (Environment and childhood project) scientific conferences.

Barcelona (Spain)

11-12 February, 2015

- Oral communication: Characterization of exposure to electromagnetic fields from non-ionizing radiation in children of INMA-Gipuzkoa: preliminary data

1st ISEE-Europe Young Researchers Conference on Environmental Epidemiology

Barcelona (Spain)

20-21 September, 2014

- Poster: Mobile phone antennas: localization and proximity to sensitive areas in the INMA-Gipuzkoa study area