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Radiofrequency electromagnetic fields, screen time, and emotional and behavioural problems in 5-year-old children

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A B S T R A C T

Background: Little is known about the exposure of young children to radiofrequency electromagnetic fields (RF-EMF) and potentially associated health effects. We assessed the relationship of RF-EMF exposure from different sources and screen time exposure with emotional and behavioural problems in 5-year-old children.
Methods: Cross-sectional study including 3102 children aged 5 years from the Amsterdam Born Children and their Development (ABCD) study, in the Netherlands. Residential RF-EMF exposure from mobile phone base stations was estimated with a 3D geospatial radio wave propagation model. Residential presence of RF-EMF indoor sources (cordless phone base stations and Wireless Fidelity (WiFi)), children's mobile phone and cordless phone calls and screen time exposure (computer/video game and television watching) was reported by the mother. Teachers (n = 2617) and mothers (n = 3019) independently reported child emotional and behavioural problems using the Strengths and Difficulties Questionnaire.
Results: No associations were found between mobile phone and cordless phone calls and emotional and behavioural problems. Children exposed to higher RF-EMF levels from mobile phone base stations showed higher odds of maternal-reported emotional symptoms (OR 1.82, 95%CI 1.07 to 3.09). Children with cordless phone at home had lower odds of teacher-reported problematic prosocial behaviour (OR 0.68, 95%CI 0.48 to 0.97) and of maternal-reported peer relationship problems (OR 0.61, 95% CI 0.39 to 0.96). Children who watched television ≥1.5 h/day had higher odds of maternal-reported hyperactivity/inattention (OR 3.13, 95%CI 1.43 to 6.82).
Conclusion: Mobile phone and cordless phone calls, which lead to peak RF-EMF exposures to the head, were not associated with any emotional and behavioural problems in 5-year-old children. Environmental RF-EMF exposure from mobile phone base stations and from indoor sources and television watching, which both contribute very little to RF-EMF exposure, were associated with specific emotional and behavioural problems but mainly when reported by the mothers. We cannot, however, discard residual confounding or reverse causality. Further longitudinal research in particular as children will increase the use of telecommunication devices with the age may help to better understand the exact contribution of the different RF-EMF exposure sources if any. Moreover, a thorough control for confounding is essential for a correct interpretation of the studies on screen time and emotional and behavioural problems.

1. Introduction

With the introduction of mobile phones and other modern telecommunication technology, radiofrequency electromagnetic fields (RF-EMF) have become a near-ubiquitous environmental exposure. Main exposure sources include mobile and cordless phones, outdoor sources (i.e. mobile phone base station and broadcast antennas), and indoor sources (i.e. cordless phone base stations and Wireless Fidelity (WiFi) access points). Mobile and cordless phone calls have been reported to be the primary contributor to brain exposure from RF-EMF (Roser et al., 2015). Although current evidence does not allow definitive conclusion on the potential biological effects of RF-EMF exposure, possible

Abbreviations: RF-EMF, Radiofrequency electromagnetic fields; ABCD, Amsterdam Born Children and their Development study; DASS, Depression Anxiety Stress Scale; LTE, Long Term Evolution technology; NOSI, Nijmeegse Ouderlijke Stress Index; SDQ, Strengths and Difficulties Questionnaire; WiFi, Wireless Fidelity

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neurodevelopment effects are of concern (World Health Organization, 2010) in particular since children are more vulnerable to environmental exposures because of their developing nervous system (Rice and Barone, 2000) and the maximum specific absorption rate (SAR) of RF-EMF energy from mobile devices in the most exposed area of the brain tends to be higher in children for anatomical reasons (the ear and skull of the child are thinner than those of adults and the antenna is in closer proximity to the brain) (Wiart et al., 2008).

Regarding children and adolescents' own mobile phone use for calling, one of the main contributors of RF-EMF exposure to the head (Roser et al., 2015), studies have produced heterogeneous results with some studies reporting more emotional and behavioural problems (Byun et al., 2013; Divan et al., 2012, 2008; Sudan et al., 2016), and others reporting no association (Mathers et al., 2009; Roser et al., 2016b). Associations between mobile phone use, in particular for other uses than calling, and emotional and behavioural problems might be explained by exposure to RF-EMF (Birks et al., 2018) or by problematic/addictive use of the phone (Roser et al., 2016a). A couple of studies that looked at other uses of mobile phones than calling found that higher time gaming was associated with behaviour problems in children at 7–12 years old (Byun et al., 2013; Calvente et al., 2016). In line with these findings, computer/video games and television watching has also been associated with emotional and behavioural problems in children and adolescents (Mathers et al., 2009; Mundy et al., 2017; Nikkelen et al., 2014; Parkes et al., 2013; Verlinden et al., 2012). Furthermore, environmental RF-EMF exposure from outdoor and indoor sources which contribute very little to RF-EMF to the head (Birks et al., 2018; Roser et al., 2015) was associated with child and adolescent emotional and behavioural problems in a German study (Thomas et al., 2010) but not in a Swiss study (Roser et al., 2016b) and a Spanish study (Calvente et al., 2016).

Therefore, the aim of the present study was to separately assess the association of RF-EMF exposure from different sources, including environmental exposure from mobile phone base stations and indoor sources and mobile phone and cordless phone calls, and two proxies of how much time children spend looking at screens, in particular computer/video games use and television watching, with emotional and behavioural problems in 5-year-old children in a large population-based cohort study. Mobile phone and cordless phone calls lead to peak RF-EMF exposures to the head while environmental RF-EMF exposure from mobile phone base stations and indoor sources, computer/video games use, and television watching contribute very little to RF-EMF exposure (Lauer et al., 2013; Roser et al., 2015). Thus, similar effect estimates for mobile phone and cordless phone calls and stronger effect estimates for mobile phone and cordless phone calls than for screen time exposure would suggest that associations with emotional and behavioural problems are due to RF-EMF exposure. On the contrary, associations for screen time exposure and no effects for mobile phone and cordless phone calls would indicate that associations with emotional and behavioural problems are driven by screen time related problematic behaviours. We have no prior assumptions regarding environmental RF-EMF exposure since no biological mechanisms have been established.

2. Material and methods

2.1. Study design and population

This study was embedded in the Amsterdam Born Children and their Development (ABCD) Study (www.abcd-study.nl). ABCD is a community-based prospective cohort study that examines the relationship of maternal lifestyle and psychosocial determinants during pregnancy, to multiple aspects of development and health of the child (van Eijsden et al., 2011). Between January 2003 and March 2004, 8266 pregnant women living in Amsterdam were enrolled during their first prenatal visit to an obstetric care provider (general practitioner, midwife or gynaecologist) (67% of those invited) (Appendix Fig A.1). Children's emotional and behavioural problems and information on screen time exposure were collected via a postal questionnaire when children were 5 years old. When children were 7 years old a postal or web questionnaire included retrospective information on RF-EMF exposure sources pertaining to the time point of the emotional and behavioural problems assessment. A total of 3102 children with available data on at least one exposure and at least one outcome variable were included. Ethical approval was obtained from the Central Committee on Research Involving Human Subjects in The Netherlands, the Medical Ethics Review Committees of the participating hospitals, and the Registration Committee of the Municipality of Amsterdam.

2.2. Residential RF-EMF exposure from mobile phone base stations

We used NISMap (Bürgi et al., 2010; Beekhuizen et al., 2013, 2014; Huss et al., 2015), a 3D geospatial radio wave propagation model, to calculate residential RF-EMF exposure from mobile phone base stations at the time point of the emotional and behavioural problems assessment as previously published (Guxens et al., 2016; Huss et al., 2015). In brief, NISMap estimates RF-EMF exposure using detailed characteristics of antennas and the 3D geometry of the urban environment and including shielding and diffraction of the radio waves by buildings. Exposure to the downlink component of the three mobile phone communication bands (GSM900, GSM1800, and UMTS) was assessed with a national mobile phone base stations data set from 2011. At the time of the study, Long Term Evolution technology (LTE, also called 4G) was not yet implemented in the Netherlands. RF-EMF exposure at the height above ground of the room in which children spent most of their time, i.e. their bedroom, was calculated. NISMap has been validated with outside, inside, and personal measurements, showing reliable rank-order predictions of downlink exposure (Beekhuizen et al., 2014, 2013; Martens et al., 2015). Continuous RF-EMF exposure levels were categorized as low ($< 50^{th}$ percentile), medium (50^{th}-90^{th} percentile), and high ($> 90^{th}$ percentile).

2.3. Residential RF-EMF indoor sources

We asked mothers about presence or absence of residential RF-EMF indoor sources (i.e. cordless phone base stations and WiFi) at the time point of the emotional and behavioural problems assessment.

2.4. Mobile phone calls, cordless phone calls

We asked mothers about the frequency of mobile and cordless phone calls of their child at the time point of the emotional and behavioural problems assessment. We categorized the exposure in 4 groups based on the distribution in our study population: none, < 1 call/week, 1–2 calls/week, ≥ 3 calls/week for mobile and cordless phone calls.

2.5. Screen time exposure: computer/video games use and television watching

At the same time point when emotional and behavioural problems were assessed, we asked mothers about the duration of computer/video games use including computer, Playstation, and Xbox at home or at a friend's house and television watching including television, DVD, and video at home or at a friend's house of their child. We categorized the exposure in 4 groups based on the distribution in our study population: none, < 0.5 h/day. 0.5–1 h/day, and ≥ 1 h/day for computer/video games use and < 0.5 h/day, 0.5–1 h/day, 1–1.5 h/day, and ≥ 1.5 h/day for television watching.

2.6. Children's emotional and behavioural problems

We assessed children's emotional and behavioural problems using the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997).

The SDQ was filled in by primary school teachers (n = 2617) and mothers (n = 3019). The SDQ is a short screening questionnaire suitable for children aged 4–16 years. The questionnaire consists of 25 items with scaled responses (very true, partly true, not true) divided in 5 subscales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, and prosocial behaviour. All items, except prosocial behaviour, added together formed the total difficulties score that represented overall emotional and behavioural problems. Children were classified as normal, borderline, and abnormal for overall emotional and behavioural problems and the 5 subscales based on validated cut-offs (Goodman, 1997).

2.7. Potential confounding variables

We selected potential confounding variables *a priori* based on previous literature (Calvente et al., 2016; Divan et al., 2008, 2012; Guxens et al., 2016; Huss et al., 2015; Roser et al., 2016b; Sudan et al., 2016) using directed acyclic graphs (Hernán et al., 2002). At enrolment, information on maternal country of birth was obtained by questionnaire. Child's sex was obtained from child health care registries. When children were 5 years old, information on maternal characteristics at that time point including age, educational level (based on the years after primary school: high (≥10 years), medium (6–9years), low (≤5 years)), weight and height, current tobacco use, current alcohol consumption, depression, anxiety, stress, and mother-to-child attachment, as well as parental financial situation, child age, and number of siblings of the child was obtained by questionnaire. Maternal body mass index was calculated (kg/m^2). Maternal depression, anxiety, and stress when the children were 5 years old were assessed using the Depression Anxiety Stress Scale (DASS) (Lovibond and Lovibond, 1995). Mother-child attachment was measured using the attachment subscale of the parent domain of the Nijmeegse Ouderlijke Stress Index (NOSI) (De Brock et al., 1992). Higher DASS scores indicate greater levels of depression, anxiety, or stress, whereas a higher mother-child attachment score reflects poorer attachment. Besides individual socioeconomic position indicators (maternal education and parental financial situation) we estimated an area-based socioeconomic position indicator by matching children's addresses at 5 years old with a map of the percentage of persons with a low income (< 40th percentile of the Dutch income distribution) at neighbourhood level (Central Bureau of Statistics, 2001).

2.8. Statistical analysis

Among children with available data on at least one exposure and at least one outcome variable (n = 3102), we had a low percentage of missing values of potential confounding variables (< 10%). We performed multiple imputation of missing values of potential confounding variables using chained equations where 25 completed datasets were generated and analysed using the standard combination rules for multiple imputation (Appendix Table A.1) (Spratt et al., 2010; Sterne et al., 2009). Distribution of potential confounding variables in imputed datasets were similar to those observed (data not shown).

We used logistic regression models to assess the association between each exposure variable and each emotional and behavioural problem scale (normal vs. borderline/abnormal and normal vs. abnormal, where in this second analysis, children with borderline problems were not included). Models were first run unadjusted and then adjusted for all potential confounding variables described above that were selected *a priori* based on previous literature and using a directed acyclic graph. We also identified which was the minimum set of confounding variables that changed the effect estimates from the unadjusted models to the fully adjusted models (the models adjusted for all potential confounding variables described above) using a statistical approach with the forward stepwise procedure. Statistical tests of hypotheses were two-tailed with significance set at p-value < 0.05. Statistical analyses were conducted using STATA (version 12.0; StataCorporation, College Station, TX, USA).

3. Results

Overall, 88.7% of children had a cordless phone at home and 76.4% had WiFi (Table 1). Around 6.5% of the children made 1–2 calls/week with a mobile phone and 4.1% ≥ 3 calls/week. Regarding cordless phone use, 17.7% of the children made 1–2 calls/weeks and 9.4% ≥ 3 calls/week. A total of 5.4% of the children used computer/video games > 1 h/day whereas 20.4% of the children watched television ≥1.5 h/day. We observed low correlations between all exposure variables (between −0.07 and 0.14, with different level of statistical significance from non-significant to a p-value < 0.001), except between mobile and cordless phone calls and between computer/video game use and television watching where correlations were moderate (0.40 and 0.28, respectively, both with a p-value < 0.001) (Appendix Table A.2). Overall, 9.9% of the children were classified as having overall borderline/abnormal emotional and behavioural problems based on teacher reports, while this percentage was 3.6% based on maternal reports (Appendix Table A.3). Correlations between teacher and maternal report were moderate to low, with 0.21 for the overall problems and between 0.11 and 0.26 for the subscales. Children included in the present analysis had families with a higher socioeconomic position than those not included (Appendix Table A.4).

Table 1
. Distribution of radiofrequency electromagnetic fields exposure sources and screen time exposre

	Total sample (n = 3102)	
	Distribution* (%)	Missing (N (%))
Radiofrequency electromagnetic fields exposure sources		
Mobile phone base stations		125 (4.0)
< 50th percentile	52.4	
50-90th percentile	37.6	
> 90th percentile	9.9	
Cordless phone base station		788 (25.4)
No	11.3	
Yes	88.7	
WiFi		807 (26.0)
No	23.6	
Yes	76.4	
Mobile phone calls		822 (26.5)
None	51.8	
< 1 call/week	37.7	
1–2 calls/week	6.5	
≥3 calls/week	4.1	
Cordless phone calls		1,104 (35.6)
None	15.5	
< 1 call/week	57.4	
1–2 calls/week	17.7	
≥3 calls/week	9.4	
Screen time exposure		
Computer/video games use		258 (8.3)
No use	57.2	
< 0.5 h/day	18.1	
0.5–1 h/day	19.4	
≥1 h/day	5.4	
Television watching		250 (8.1)
< 0.5 h/day	8.2	
0.5–1 h/day	43.1	
1–1.5 h/day	28.3	
≥1.5 h/day	20.4	

*The percentages add up to 100% without taking into account the missing values.

Table 2
Adjusted association of radiofrequency electromagnetic fields exposure sources and screen time exposure with teacher-reported emotional and behavioural problems (borderline/abnormal *vs.* normal) in 5-year-old children.

	Teacher-reported emotional and behavioural problems (n = 2617)											
	Overall problems		Emotional symptoms		Conduct problems		Hyperactivity/inattention		Peer relationship problems		Prosocial behaviour	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Radiofrequency electromagnetic field exposure sources												
Mobile phone base stations												
< 50th percentile	1.00		1.00		1.00		1.00		1.00		1.00	
50-90th percentile	1.24	(0.93–1.65)	0.90	(0.63–1.30)	**1.37**	**(1.02–1.83)**	0.99	(0.76–1.29)	1.08	(0.76–1.54)	0.94	(0.75–1.19)
> 90th percentile	0.84	(0.51–1.38)	0.99	(0.57–1.74)	0.70	(0.40–1.21)	1.05	(0.69–1.59)	1.31	(0.78–2.19)	0.92	(0.63–1.33)
P-trend		0.815		0.776		0.875		0.901		0.329		0.543
Cordless phone base station												
No	1.00		1.00		1.00		1.00		1.00		1.00	
Yes	1.03	(0.65–1.64)	0.70	(0.39–1.24)	1.07	(0.66–1.74)	1.00	(0.66–1.53)	1.04	(0.58–1.85)	**0.68**	**(0.48–0.97)**
WiFi												
No	1.00		1.00		1.00		1.00		1.00		1.00	
Yes	0.93	(0.65–1.33)	0.72	(0.45–1.13)	1.16	(0.79–1.69)	1.04	(0.75–1.44)	0.91	(0.60–1.40)	0.87	(0.65–1.16)
Mobile phone calls												
None	1.00		1.00		1.00		1.00		1.00		1.00	
< 1 call/week	**0.67**	**(0.47–0.95)**	0.79	(0.51–1.22)	0.79	(0.56–1.12)	0.94	(0.69–1.28)	0.74	(0.49–1.12)	0.86	(0.66–1.12)
1–2 calls/week	1.09	(0.60–1.98)	0.98	(0.43–2.23)	1.00	(0.52–1.91)	1.30	(0.76–2.25)	1.44	(0.74–2.77)	0.75	(0.43–1.30)
≥3 or more calls/ week	0.70	(0.30–1.60)	0.35	(0.08–1.49)	1.32	(0.64–2.73)	1.34	(0.70–2.58)	0.49	(0.15–1.63)	1.53	(0.87–2.71)
P-trend		0.206		0.160		0.997		0.382		0.438		0.974
Cordless phone calls												
None	1.00		1.00		1.00		1.00		1.00		1.00	
< 1 call/week	1.23	(0.76–2.00)	1.15	(0.61–2.17)	1.02	(0.64–1.62)	0.92	(0.61–1.37)	1.50	(0.82–2.76)	1.14	(0.79–1.65)
1–2 calls/week	1.05	(0.58–1.92)	1.10	(0.51–2.37)	0.79	(0.44–1.44)	0.65	(0.38–1.12)	1.36	(0.66–2.82)	1.08	(0.68–1.70)
≥3 calls/week	1.36	(0.70–2.64)	0.76	(0.28–2.08)	1.20	(0.62–2.33)	1.07	(0.60–1.92)	1.40	(0.62–3.17)	0.72	(0.40–1.31)
P-trend		0.580		0.643		0.991		0.603		0.569		0.380
Screen time exposure												
Computer/video games use												
No use	1.00		1.00		1.00		1.00		1.00		1.00	
< 0.5 h/day	1.13	(0.78–1.62)	0.80	(0.50–1.29)	0.89	(0.60–1.32)	1.36	(0.99–1.88)	0.70	(0.43–1.14)	0.78	(0.58–1.05)
0.5–1 h/day	1.21	(0.86–1.70)	0.78	(0.49–1.25)	1.14	(0.80–1.61)	1.21	(0.88–1.66)	1.12	(0.75–1.69)	0.80	(0.60–1.07)
≥1 h/day	0.81	(0.45–1.45)	0.55	(0.22–1.36)	0.94	(0.52–1.69)	1.04	(0.61–1.75)	0.49	(0.22–1.10)	0.68	(0.42–1.11)
P-trend		0.759		0.121		0.771		0.327		0.445		**0.039**
Television watching												
< 0.5 h/day	1.00		1.00		1.00		1.00		1.00		1.00	
0.5–1 h/day	0.76	(0.45–1.30)	1.01	(0.50–2.04)	0.61	(0.37–1.00)	0.96	(0.59–1.57)	0.79	(0.43–1.46)	0.85	(0.57–1.28)
1–1.5 h/day	0.93	(0.54–1.60)	1.41	(0.70–2.87)	0.79	(0.48–1.32)	0.97	(0.58–1.61)	0.85	(0.45–1.60)	0.79	(0.52–1.21)
≥1.5 h/day	0.97	(0.55–1.71)	1.10	(0.51–2.38)	0.66	(0.38–1.14)	1.00	(0.59–1.71)	0.73	(0.37–1.43)	0.83	(0.53–1.30)
P-trend		0.399		0.424		0.738		0.891		0.541		0.462

Odds Ratio (95% Confidence Interval) from logistic regression models represent the odds for the children classified as "borderline" or "abnormal" for having emotional and behavioural problems compared to the ones classified as "normal". Models were adjusted for maternal education, area-level indicator of socio-economic status, country of birth, age, body mass index, tobacco use, alcohol consumption, depression, anxiety, and stress, mother-child attachment, parental financial situation, and child's sex, number of siblings, and age at emotional and behavioural problems questionnaire.**Bold:** p-value < 0.05.

In adjusted models, no associations were found between any RF-EMF sources or any screen time exposure and teacher-reported emotional and behavioural problems scales, except that children with cordless phone at home had lower odds of borderline/abnormal prosocial behaviour (OR 0.68, 95%CI 0.48 to 0.97) (Table 2). Regarding maternal-reported emotional and behavioural problems, children exposed to higher RF-EMF levels from mobile phone base stations showed higher odds of borderline/abnormal emotional symptoms (OR 1.82, 95%CI 1.07 to 3.09) and children with cordless phone at home had lower odds of borderline/abnormal peer relationship problems (OR 0.61, 95%CI 0.39 to 0.96) (Table 3). Children who watched television ≥1.5 h/day had higher odds of maternal-reported borderline/abnormal hyperactivity/inattention (OR 3.13, 95%CI 1.43 to 6.82) compared to those that watched television < 0.5 h/day.

In contrast to the adjusted models, we observed a higher number of associations between computer/video games use and television watching and several emotional and behavioural problems reported by teachers or mothers when models were not adjusted for the potential confounding variables (Appendix Tables A.5-A.6). Main confounding variables of these associations were maternal education, maternal anxiety, mother-child attachment, and child's sex (Appendix Tables A.7-A.8).

When abnormal emotional and behavioural problems were assessed, the only two associations were between children exposed to higher RF-EMF levels from mobile phone base stations and maternal-reported emotional symptoms (OR 2.08, 95%CI 1.03 to 4.19) and between children who watched television ≥1.5 h/day and maternal-reported hyperactivity/inattention (OR 3.13, 95%CI 1.16 to 8.43) (Appendix Tables A.9-A.10).

4. Discussion

In the present study we found no association between mobile phone or cordless phone calls and emotional and behavioural problems in 5-year-old children. Higher residential RF-EMF exposure from mobile phone base stations was associated with higher odds of emotional

Table 3
Adjusted association of radiofrequency electromagnetic fields exposure sources and screen time exposure with maternal-reported emotional and behavioural problems (borderline/abnormal *vs.* normal) in 5-year-old children.

	Maternal-reported emotional and behavioural problems (n = 3019)											
	Overall problems		Emotional symptoms		Conduct problems		Hyperactivity/inattention		Peer relationship problems		Prosocial behaviour	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Radiofrequency electromagnetic field exposure sources												
Mobile phone base stations												
< 50th percentile	1.00		1.00		1.00		1.00		1.00		1.00	
50-90th percentile	1.33	(0.85–2.09)	1.09	(0.74–1.62)	1.08	(0.83–1.41)	1.09	(0.81–1.47)	1.15	(0.84–1.57)	0.94	(0.72–1.24)
> 90th percentile	1.27	(0.64–2.53)	**1.82**	**(1.07–3.09)**	0.70	(0.43–1.13)	1.16	(0.73–1.85)	1.26	(0.78–2.03)	0.96	(0.61–1.48)
P-trend		0.278		0.060		0.439		0.446		0.266		0.718
Cordless phone base station												
No	1.00		1.00		1.00		1.00		1.00		1.00	
Yes	0.89	(0.45–1.76)	1.15	(0.59–2.23)	1.17	(0.75–1.84)	1.18	(0.73–1.92)	**0.61**	**(0.39–0.96)**	0.81	(0.53–1.26)
WiFi												
No	1.00		1.00		1.00		1.00		1.00		1.00	
Yes	1.14	(0.64–2.02)	1.19	(0.71–1.99)	1.29	(0.91–1.83)	0.91	(0.64–1.32)	0.91	(0.62–1.33)	1.11	(0.78–1.59)
Mobile phone calls												
None	1.00		1.00		1.00		1.00		1.00		1.00	
< 1 call/week	1.44	(0.84–2.45)	1.10	(0.70–1.71)	0.93	(0.68–1.27)	0.98	(0.70–1.39)	**0.61**	**(0.42–0.91)**	0.96	(0.71–1.31)
1–2 calls/week	0.92	(0.33–2.62)	1.29	(0.60–2.78)	1.01	(0.57–1.78)	0.67	(0.33–1.37)	0.67	(0.32–1.39)	0.99	(0.54–1.79)
≥3 calls/week	1.67	(0.60–4.69)	1.03	(0.38–2.84)	0.76	(0.36–1.62)	0.80	(0.36–1.79)	1.23	(0.59–2.56)	0.49	(0.19–1.28)
P-trend		0.334		0.629		0.544		0.365		0.338		0.296
Cordless phone calls												
None	1.00		1.00		1.00		1.00		1.00		1.00	
< 1 call/week	0.72	(0.35–1.50)	1.32	(0.67–2.62)	1.19	(0.76–1.85)	1.05	(0.64–1.71)	0.81	(0.48–1.35)	1.32	(0.83–2.08)
1–2 calls/week	0.70	(0.28–1.76)	1.77	(0.82–3.82)	1.32	(0.78–2.23)	1.02	(0.56–1.85)	0.62	(0.31–1.23)	1.07	(0.61–1.88)
≥3 calls/week	0.99	(0.37–2.64)	0.76	(0.27–2.17)	1.17	(0.62–2.19)	1.84	(0.97–3.46)	1.24	(0.62–2.47)	1.14	(0.59–2.21)
P-trend		0.913		0.896		0.478		0.101		0.894		0.987
Screen time exposure												
Computer/video games use												
No use	1.00		1.00		1.00		1.00		1.00		1.00	
< 0.5 h/day	1.11	(0.62–1.99)	0.92	(0.55–1.54)	1.26	(0.90–1.78)	1.16	(0.79–1.71)	1.14	(0.76–1.71)	0.79	(0.54–1.13)
0.5–1 h/day	0.94	(0.54–1.63)	1.26	(0.80–1.99)	1.03	(0.73–1.44)	**1.44**	**(1.01–2.06)**	1.16	(0.79–1.69)	0.91	(0.65–1.28)
≥1 h/day	0.83	(0.37–1.88)	0.86	(0.37–1.99)	1.10	(0.64–1.88)	1.23	(0.68–2.21)	0.71	(0.39–1.30)	1.27	(0.74–2.18)
P-trend		0.692		0.660		0.675		0.085		0.853		0.961
Television viewing												
< 0.5 h/day	1.00		1.00		1.00		1.00		1.00		1.00	
0.5–1 h/day	1.79	(0.52–6.18)	1.36	(0.60–3.09)	0.72	(0.43–1.20)	1.49	(0.69–3.22)	1.37	(0.66–2.87)	1.30	(0.73–2.30)
1–1.5 h/day	1.43	(0.40–5.09)	1.27	(0.55–2.96)	0.88	(0.52–1.50)	1.84	(0.84–3.99)	1.58	(0.75–3.34)	1.37	(0.76–2.46)
≥1.5 h/day	2.56	(0.73–8.93)	1.46	(0.61–3.47)	0.96	(0.55–1.66)	**3.13**	**(1.43–6.82)**	1.63	(0.77–3.48)	1.49	(0.80–2.77)
P-trend		0.126		0.584		0.317		**< 0.001**		0.183		0.234

Odds Ratio (95% Confidence Interval) from logistic regression models represent the odds for the children classified as "borderline" or "abnormal" for having emotional and behavioural problems compared to the ones classified as "normal". Models were adjusted for maternal education, area-level indicator of socioeconomic status, country of birth, age, body mass index, tobacco use, alcohol consumption, depression, anxiety, and stress, mother-child attachment, parental financial situation, and child's sex, number of siblings, and age at emotional and behavioural problems questionnaire.**Bold:** p-value < 0.05.

symptoms when reported by the mothers and children with cordless phone at home had lower odds of problematic prosocial behaviour and of peer relationship problems when reported by the teachers and mothers respectively. More hours of television watching were associated with higher odds of maternal-reported hyperactivity/inattention, whereas computer/video game use was not related to child emotional and behavioural problems. Effect estimates of computer/video game use and television watching were strongly confounded by some family characteristics including maternal educational level, mother-child attachment, maternal anxiety, and child's sex.

Strengths of our study include the assessment of different RF-EMF exposure sources as well as screen time exposure which helped to disentangle between exposure to RF-EMF or problematic use of the devices, the assessment of child emotional and behavioural problems by teachers and mothers which is more informative than single-informant data since emotional and behavioural problems may be highly situational, as shown in our study by the low to moderate correlation between them, the availability of several potential confounding variables related to the use of the devices and to child emotional and behaviour problems, including socioeconomic, psychological, and lifestyle factors, and the relative large sample size of children from a population-based birth cohort study.

A limitation of our study is its cross-sectional design. Reverse causality could not be discarded in the observed association between television watching and emotional and behavioural problems where children with higher emotional and behavioural problems could have a higher use of television watching. Another limitation is the potential for differential recall bias of child mobile and cordless phone calls related to the outcome. However, child emotional and behavioural problems were assessed two years before the mother reported phone use, and mothers did not receive feedback on the emotional and behavioural problems of their children. Thus, it would be unclear whether mothers could have systematically underestimated or overestimated their children's phone use report. In addition, we also evaluated teacher-reported emotional and behavioural problems which were not strongly related to maternal-reported phone use as shown in our study. Our study focused on the frequency of phone calls as proxy of RF-EMF exposure to the head. We also collected information on the duration of the mobile

phone and cordless phone calls which would be a better measure of RF-EMF exposure. However, we did not have enough contrast to explore its relationship with child emotional and behavioural problems (children only called for few minutes, 62% and 69% of the children reported < 5min/call on mobile phone and cordless phone, respectively). Lastly, we cannot discard that our findings were a result of chance findings since we performed a large number of analyses. Nevertheless, we based our conclusions on the general patterns of associations observed in the study (Perneger, 1998; Rothman, 1990).

Only few previous studies assessed the association between mobile phone calls and child emotional and behavioural problems leading to inconsistent results. A Danish study showed that children's frequency of mobile phone calls at 7 years old were associated with maternal-reported emotional and behavioural problems at the same age (Divan et al., 2012, 2008) and at 11 years old even when children with emotional and behavioural problems at 7 years old were excluded (Sudan et al., 2016). A Korean study also found that both frequency and duration of mobile phone calls was associated with increased parental-reported attention deficit and hyperactivity at 9–11 years old (Byun et al., 2013). However, another study in Switzerland did not observe associations between children's duration of mobile phone or cordless phone calls or an estimated RF-EMF dose to the brain or the whole-body and parental- or self-reported emotional and behavioural problems at 12–17 years old (Roser et al., 2016b). In contrast with these previous studies, we investigated younger children and we did not observe an association between frequency of mobile phone or cordless phone calls and higher scores of emotional and behavioural problems, using either maternal or teacher reports. As both mobile phone and cordless phone calls leads to peak head RF-EMF exposure (Lauer et al., 2013; Roser et al., 2015), we hypothesize that RF-EMF exposure is not related to child emotional and behavioural problems at this young age. A couple of studies looked at other uses of mobile phone such as texting and gaming, which lead to very low RF-EMF exposure to the head, and they found that higher time gaming was associated with an increased parental- or self-reported emotional and behavioural problems at 9–17 years old (Byun et al., 2013; Roser et al., 2016b). In another study, higher duration of total use of a mobile phone, including calling, texting, use of internet, and gaming, was related to increased levels of depression (Bickham et al., 2015; Ikeda and Nakamura, 2014) and inattention (Zheng et al., 2014) in children at 12–20 years old, whereas in another study no association with emotional and behavioural problems was found in children at 16 years old (Mathers et al., 2009). However, a limitation of these studies is that they could not differentiate between effects from RF-EMF exposure due to calling and effects from a problematic use of mobile phones.

We also found an association between residential RF-EMF exposure from mobile phone base stations and higher odds of emotional symptoms only when reported by the mothers. No previous studies have specifically assessed this exposure, but another cross-sectional study which carried out personal measurements of total RF-EMF from several sources in children at 8–17 years old found that children with higher RF-EMF levels had an increased overall emotional and behavioural problems and conduct problems (Thomas et al., 2010). These findings differ from ours in that we found an association only with emotional symptoms. If an increased risk of emotional and behavioural problems was indeed due to RF-EMF exposure, we would expect stronger effect estimates from mobile phone or cordless phone calls instead of environmental RF-EMF levels from mobile phone base stations, given that the exposure to the head is much lower (Lauer et al., 2013). However, it is difficult to compare the amount of exposure that children would receive from each source since exposure has different patterns depending on factors not collected in our study, such as the service type used for calling or the phone type.

In contrast, children with a cordless phone at home, an indoor source of environmental RF-EMF exposure, showed lower odds of problematic prosocial behaviour and peer relationship problems. We have no explanation for this finding. We need to take into account that indoor RF-EMF sources contribute very little to RF-EMF exposure in children (Roser et al., 2017) and that residual confounding cannot be discarded as exposure to indoor sources of RF-EMF might be strongly related to better socioeconomic, psychological, and life-style family characteristics. In a previous study we showed that children with presence of residential RF-EMF indoor sources, including cordless phone base station and WiFi, had a higher proportion of parents with a better financial situation, a higher proportion of mothers with higher education, who smoked less and with lower body mass index, and a lower proportion of mother with depression and anxiety symptoms compared to those children without RF-EMF indoor sources (Guxens et al., 2016). Overall, it is difficult to correctly interpret these results since no biological explanation exists for associations between environmental RF-EMF exposure from outdoor or indoor sources and emotional and behavioural problems.

In our study, we found an association between television watching and hyperactivity/inattention only based on maternal reports after adjusting for several potential confounding variables. This finding is in line with several previous studies (Nikkelen et al., 2014; Verlinden et al., 2012). Different hypotheses have been suggested to explain this relationship, including the media content, the fast-paced media, or the time spent consuming media which might displace other cognitive stimulating activities (Nikkelen et al., 2014). However, in studies evaluating effects of screen time exposure on child emotional and behavioural problems, residual confounding is of concern as both exposure and outcome variables are strongly related to several family characteristics. As shown in our study, in the unadjusted models television watching and computer/video games use were associated with several emotional and behavioural problems reported by the teachers or the mothers. However, after adjusting for a small set of key confounding variables, including maternal education, mother-child attachment, maternal anxiety, and child sex, associations moved towards unity. Similar patterns have been observed in the association between television watching and computer/video games and emotional and behavioural problems in the Millenium Cohort Study in the UK (Parkes et al., 2013), which also pointed out the importance of including appropriate potential confounding variables in studies evaluating these research questions.

5. Conclusions

Mobile phone and cordless phone calls, which lead to peak RF-EMF exposures to the head, were not associated with any emotional and behavioural problem in 5-year-old children. We found that environmental RF-EMF exposure from mobile phone base stations and television watching, which both contribute very little to RF-EMF exposure, were associated with higher odds of specific types of emotional and behavioural problems at this young age, but only when reported by the mothers. Moreover, children with cordless phone at home had lower odds of problematic prosocial behaviour and peer relationship problems. We cannot, therefore, discard residual confounding or reverse causality. As new telecommunication devices continue evolving and their use will increase across childhood and adolescence, further research on better understanding the potential association of the different RF-EMF exposure sources with child neurodevelopment, including longitudinal studies, is warranted in order to develop preventive recommendations and guidelines. Moreover, a thorough control for confounding is essential for a correct interpretation of the studies on screen time and emotional and behavioural problems.

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Conflicts of interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2018.09.006.

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