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Letter to the Editor

Radiofrequency Exposure Levels in Amsterdam Schools

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The use of wireless communication devices has rapidly increased in modern society. Existing mobile phone networks are continuously being expanded to facilitate the growing demand for wireless communication, while simultaneously novel technologies are being introduced. Adults as well as children are using (smart) phones, tablets, and other devices on a daily basis [Südwest, 2013]. The increase in use of wireless communication devices has led to an increase in the number of people exposed to radiofrequency electromagnetic fields (RF-EMF). Wireless local area networks (WLAN) based on WiFi technology are gaining popularity in schools, where devices such as tablets and laptops are being introduced as educational tools. Information on RF-EMF exposure of children in schools is sparse, with studies mostly sampling a limited number of school locations [Juhász et al., 2011; Markakis and Samaras, 2013; Vermeeren et al., 2013; Verloock et al., 2014a,b]. The objective of our study was to assess indoor RF-EMF levels to which children are exposed in a large number of primary schools in Amsterdam.

Measurements were taken at 102 out of 213 primary schools in the Amsterdam area, the Netherlands, between July 2011 and 2012 (Fig. S1, Supplementary Online Materials). The measurement campaign was nested within the Amsterdam Born Children and their Development (ABCD) study [van Eijsden et al., 2011]. We selected primary schools that were located in the Amsterdam area and that were attended by at least one child participating in the ABCD study. Within each school, two classrooms were selected based on the presence of children participating in the ABCD study. When more than two classrooms were available, the two classrooms furthest apart were selected for RF-EMF measurements. When there was only one child participating in the study in a school, only one classroom was measured. Measurements in each classroom consisted of at least seven spot measurements of 2 min each, taking a reading once every 4 s. One measurement was taken in each corner of the room at 1.5 m above the floor and 1.5 m away from the walls. Three measurements were taken in the center of the room at 1.1, 1.5, and 1.7 m above the floor, respectively. Up to three additional spot measurements were performed in irregular shaped rooms (87 classrooms). These additional spot measurements were taken at a height of 1.5 m above the floor. This method was adapted from measurement recommendations by CENELEC [2008] and used previously by Bürgi et al. [2010], who found that this method provides stable average exposure estimates.

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An adjustable wooden tripod was used to minimize interference of radio waves by metallic objects. Study assistants and any other persons present in the room were asked to turn off their mobile phones and to keep a distance of at least 1.5 m during measurements to minimize interference with background exposure in the room. Measurements were taken in the afternoon directly after school hours, usually between 13:00 and 17:00 h. The presence of DECT (digital enhanced cordless telecommunications) or WiFi base stations in or within 5 m of the classroom was registered. An EME SPY 140 exposure meter (SATIMO, EMF Measurement & Simulation Tools, Brest, France) with the ability to measure 14 different frequency bands, ranging from FM to WiFi 5G, was used. The detection limit for mobile phone and WiFi frequency bands is $6.64^{*}10^{-2}\ \mu W\ m^{-2}$ while the detection limits for other bands are higher (i.e., less sensitive): TETRA ($2.65^{*}10^{-1}\ \mu W\ m^{-2}$), TV3 ($1.06\ \mu W\ m^{-2}$), and FM ($6.63\ \mu W\ m^{-2}$). The expanded uncertainty was provided by the manufacturer following the revised ECC Recommendation (02)04 [Electronic Communications Committee, 2007], including calibration uncertainty, axial isotropy, and filters, and can be found in Table 1. It was calibrated before the measurement campaign. The SATIMO device registers measurements below the detection limit as the value of the detection limit. For statistical analysis, measurements below the respective detection limits (censored values) were imputed using the robust regression order statistics (ROS) method per spot measurement sample. In this method, a log-normal distribution is fitted to the observed data and used to model censored values. Modeled censored values are then combined with observed values [Röösli et al., 2008]. All statistical calculations were performed using R version 3.2.2 [R Core Team, 2015].

To evaluate contributions of indoor or outdoor sources to total exposure, the 14 frequency bands were additionally grouped into six categories: (i) broadcast (FM, TV3, TV45); (ii) TETRA; (iii) mobile phone uplink (GSM900, GSM1800, UMTS); (iv) mobile phone downlink (GSM900, GSM1800, UMTS); (v) DECT (i.e., cordless landline phones); and (vi) WiFi (WiFi 2G, WiFi 5G, WiMAX). A second distinction was made between outdoor sources (broadcast, TETRA, mobile phone download) and indoor sources (mobile phone upload, DECT, WiFi).

Selected primary schools were located throughout the city of Amsterdam. The 102 schools accounted for 48% of all primary schools in Amsterdam. Spot measurements were taken in 201 classrooms. In general, two classrooms were measured, with an additional classroom measured in the first two schools visited, and a single classroom measured in five schools that were attended by only a single ABCD study child. The average power density across all schools was 70.5 [Interquartile range 8.9–58.1] $\mu W\ m^{-2}$ ($0.16\ V\ m^{-1}$). Figure S2 (Supplementary Online Materials) shows the cumulative distribution function. For comparison, ICNIRP guidelines [ICNIRP, 1998], which are followed in the Netherlands, vary between $28\ V\ m^{-1}$ and $61\ V\ m^{-1}$ depending on the frequency. Table 1 summarizes the measurement results for each frequency band as well as their respective contributions to total average power density. WiFi 5 GHz signals were not detected in any of the classrooms. Figure 1 shows the relative contribution of the six aforementioned categories to overall power density.

TABLE 1. Frequency Bands, Expanded Uncertainty, and Results, Average Power Density ($\mu W\ m^{-2}$) ($n = 201$)

Band	Sources	Range (MHz)	Contribution[c]	Mean	SD	Expanded uncertainty (dB)
FM	Radio	88–108	5.47%	0.94	1.70	3.77
TV3	Digital audio	173–223	0.71%	0.12	0.36	2.60
TV45	Television	380–390	3.77%	1.56	8.39	3.04
TETRA	Terrestrial trunked radio	470–830	2.53%	2.11	13.10	2.89
GSM900 UL[a]	GSM mobile devices	880–915	7.77%	2.90	12.29	2.87
GSM900 DL[a]	GSM base stations	925–960	23.37%	12.35	30.88	2.90
GSM1800 UL[a]	GSM mobile devices	1710–1785	3.33%	1.06	3.05	2.75
GSM1800 DL[a]	GSM base stations	1805–1880	14.56%	8.39	26.81	2.73
DECT	Digital enhanced cordless telephony	1880–1900	27.28%	35.18	162.18	1.85
UMTS UL[a]	3G mobile devices	1920–1980	0.81%	0.10	0.44	1.80
UMTS DL[a]	3G base stations	2110–2170	5.86%	3.43	8.69	2.22
WiFi 2G	Wireless networks	2400–2500	4.51%	2.40	11.90	2.72
WiFi 5G[b]	Wireless networks	3400–3800	–	–	–	5.93
WiMax	Wireless networks	5150–5850	0.02%	0.01	0.04	4.65

[a]Uplink (UL) and downlink (DL) from point of view of mobile device.
[b]No measurements above detection limit.
[c]Percentage of total RF-EMF levels detected.

All categories, with the exception of mobile phone downlink exposures, were strongly skewed to the right. The relative contribution varied strongly, in particular for mobile phone downlink signals (median 44.4% [Interquartile range 7.5–78.2]). TETRA and WiFi categories had small interquartile ranges, indicating low variability. They would contribute more than 50% to overall power density in only a few classrooms. Figure 2 shows overall power densities for the six categories, stratified by the recorded absence or presence of WiFi routers, or DECT base stations. The contribution of broadcast signals remained similar over all four groups, while the other categories varied more strongly. The contribution of WiFi was higher in the groups with a recorded WiFi router. Conversely, DECT contribution was highest in the group where no DECT base station or WiFi router was registered. Overall, mobile phone downlink and DECT signals contributed most to total RF-EMF levels, followed by broadcast and mobile uplink. WiFi contributed only a small fraction (4.5%) to total RF-EMF levels. The contribution to average power density from outdoor sources was somewhat higher (56.3%) compared to indoor sources (43.7%).

RF-EMF exposure levels were determined for 201 classrooms in 102 primary schools in Amsterdam, resulting in an average power density of 70.5 $\mu W\,m^{-2}$ (0.16 $V\,m^{-1}$). Main contributors to total RF-EMF levels were mobile phone downlink and DECT signals. Over half of detected signals (56.3%) originated from outdoor sources (e.g., mobile phone downlink, TETRA, broadcast). When looking at signals that originated from indoor sources (e.g., DECT, WiFi, mobile uplink), DECT was the main contributor, followed by mobile phone uplink. Most variance was explained by differences between rooms, suggesting that measuring one single classroom per school is not enough to accurately represent RF-EMF levels for the entire school building. Individual spots inside a classroom were near each other. Even so, variance within/between spots accounted for 13.0%, indicating a location-driven variation. The presence of a WiFi router and classroom floor appeared to have an effect on RF-EMF levels. The presence of a DECT base station, however, did not.

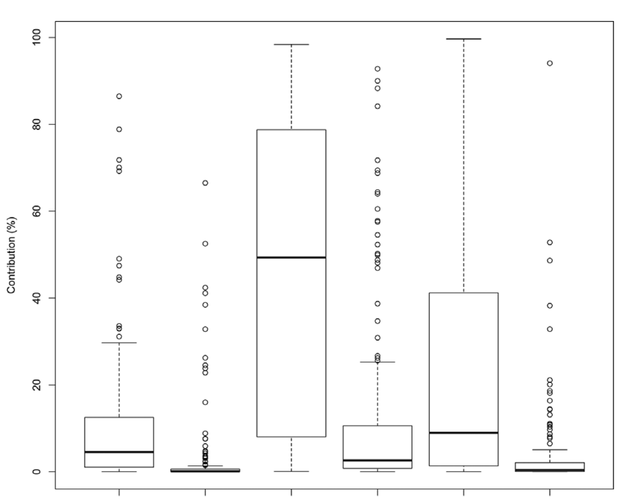

Fig. 1. Relative contribution to average power density of all six categories ($n = 201$).

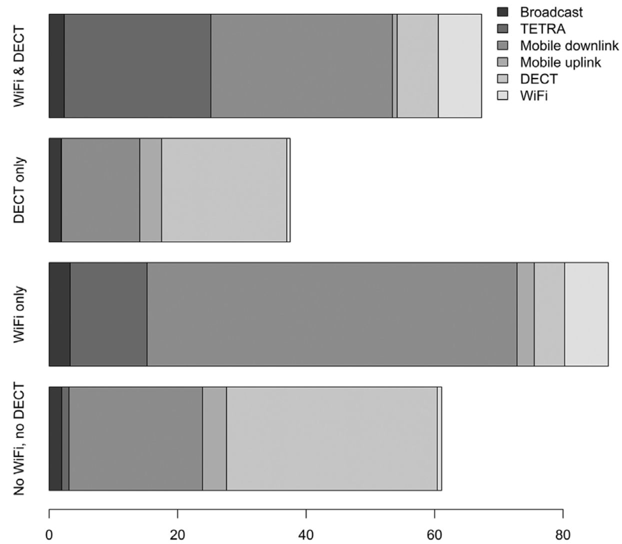

Fig. 2. Average power density ($\mu W\,m^{-2}$), stratified for presence of WiFi and/or DECT base stations. Rooms missing information on WiFi or DECT base stations were excluded from this graph ($n = 166$).

The main strength of our study was the large sample size, covering nearly half of all primary schools in Amsterdam, representing an urban setting. Limitations of our study include that measurements were done after school hours. As such, the influence of mobile communication devices used by children was not included. Mobile phones were turned off during measurements so that they would not provide an additional indoor source. This means that the contribution of indoor sources has most likely been underestimated. Since the time of our measurement campaign, LTE networks and WiFi 5 GHz have become more common; thus this exposure would likely be detected nowadays. Secondly, with 7–10 measurement spots, the measurement time per classroom was limited to 14–20 min. This means that information on temporal variation is limited. The authors previously repeated outdoor RF-EMF measurements over several months and found that exposure levels remained quite stable over time [Urbinello et al., 2014].

Other studies in school environments carried out in Belgium and Greece by Verloock et al. [2014b] and Vermeeren et al. [2013] found RF-EMF levels of $0.40\,\mathrm{V\,m^{-1}}$ and $0.35\,\mathrm{V\,m^{-1}}$, respectively, roughly double the RF-EMF levels that were measured in this study. Possibly these differences could have been introduced by differences in measurement protocols. Verloock et al. [2014b] focused their selection on schools with WiFi availability and the presence of other indoor RF sources. Similarly, Vermeeren et al. [2013] performed measurements in rooms where highest exposure was expected (i.e., containing DECT base stations and/or WiFi access points). It was found that on average 43.4% of RF-EMF levels originated from indoor sources, with DECT being the main contributor. When comparing average contributions to previously reported levels, both similarities and differences could be found. It was found that the main overall contributor to total exposure was mobile phone downlink, which is in line with results from Markakis and Samaras [2013] and Vermeeren et al. [2013]. Similarly, Frei et al. [2009] found mobile phone downlink to be the main contributor during personal exposure measurements. The contribution of other bands differs, with DECT contribution in other publications ranging from 4% to 33% [Frei et al., 2009; Markakis and Samaras, 2013; Vermeeren et al., 2013]. While absolute levels were low, indoor sources may be of interest because they represent a source of exposure that can be influenced/changed.

Low RF-EMF levels were found in a large sample of primary schools in Amsterdam, with mobile phone downlink (37.9%) and DECT (27.3%) signals being the major contributors. While our analysis indicates that presence of a WiFi router has a small influence on RF-EMF levels, absolute levels were low with WiFi signals in classrooms contributing just 4.5% of total RF-EMF levels. While the absolute RF-EMF levels were low, some influence can still be exerted by controlling indoor sources.

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REFERENCES

Bürgi A, Frei P, Theis G, Mohler E, Braun-Fahrländer C, Fröhlich J, Neubauer G, Egger M, Röösli M. 2010. A model for radiofrequency electromagnetic field predictions at outdoor and indoor locations in the context of epidemiological research. Bioelectromagnetics 31:226–236.

CENELEC. 2008. CENELEC.EN50492: Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations. Brussels, Belgium.

Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT). 2007. ECC recommendation (02) 04 (revised Bratislava 2003, Helsinki 2007). Measuring non-ionizing electromagnetic radiation (9 kHz–300 GHz).

Frei P, Mohler E, Neubauer G, Theis G, Bürgi A, Fröhlich J, Braun-Fahrländer C, Bolte J, Egger M, Röösli M. 2009. Temporal and spatial variability of personal exposure to radio frequency electromagnetic fields. Environ Res 109: 779–785.

ICNIRP, 1998. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 74:494–522.

Juhász P, Bakos J, Nagy N, Jánossy G, Finta V, Thuróczy G. 2011. RF personal exposimetry on employees of elementary schools, kindergartens and day nurseries as a proxy for child exposures. Prog Biophys Mol Biol 107:449–455.

Markakis I, Samaras T. 2013. Radiofrequency exposure in Greek indoor environments. Health Phys 104:293–301.

R Core Team. 2015. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available from https://www.R-project.org/ [Last accessed 25 July 2016].

Röösli M, Frei P, Mohler E, Braun-Fahrländer C, Bürgi A, Fröhlich J, Neubauer G, Theis G, Egger M. 2008. Statistical analysis of personal radiofrequency electromagnetic field measurements with nondetects. Bioelectromagnetics 29: 471–478.

Südwest MF. 2013. KIM-studie 2012. Kinder medien. Computer Internet. Basisuntersuchung Zum Medienumgang:3–80 (in German).

Urbinello D, Huss A, Beekhuizen J, Vermeulen R, Roosli M. 2014. Use of portable exposure meters for comparing mobile phone base station radiation in different types of areas in the cities of Basel and Amsterdam. Sci Total Environ 468-469: 1028–1033.

van Eijsden M, Vrijkotte TG, Gemke RJ, van der Wal MF. 2011. Cohort profile: The Amsterdam born children and their development (ABCD) study. Int J Epidemiol 40:1176–1186.

Verloock L, Joseph W, Goeminne F, Martens L, Verlaek M, Constandt K. 2014a. Temporal 24-hour assessment of radio frequency exposure in schools and homes. Measurement 56:50–57.

Verloock L, Joseph W, Goeminne F, Martens L, Verlaek M, Constandt K. 2014b. Assessment of radio frequency exposures in schools, homes, and public places in Belgium. Health Phys 107:503–513.

Vermeeren G, Markakis I, Goeminne F, Samaras T, Martens L, Joseph W. 2013. Spatial and temporal RF electromagnetic field exposure of children and adults in indoor micro environments in Belgium and Greece. Prog Biophys Mol Biol 113:254–263.

SUPPORTING INFORMATION

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