Measurement of personal radio frequency exposure in Japan: the Hokkaido Study on the Environment and Children's Health

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Abbreviations

[1] RF. EMF: radio frequency electromagnetic fields, DL: downlink, UL: uplink, TDD: time division duplex, INMA: Infancia y Medio Ambiente, ADHD: attention deficit hyperactivity disorder, SDQ: strengths and difficulties questionnaire, TDS: total difficulties score

Abstract

The opportunities for exposure to radiofrequency electromagnetic fields (RF-EMF) among children are increasing. Children's exposure to RF-EMF in Japan was recorded using a personal exposure meter (ExpoM-RF), and factors associated with the exposure examined. A total of 101 children, aged 10-15 years old, participated in the prospective birth cohort "Hokkaido study". RF-EMF data were recorded in the 700 MHz-5.8 GHz frequency range for 3 days. The recorded data were summarized into six groups of frequency bands: downlink from mobile phone base stations (DL), uplink from mobile phones to a base station (UL), Wireless Local Area Network (LAN), terrestrial digital TV broadcasting (digital TV), 2.5 GHz and 3.5 GHz Time Division Duplex (TDD), 1.9 GHz TDD, and total (the summation of power density in all measured frequency bands). A questionnaire was used to document the internet environment (at home) and mobile phone usage. Personal RF-EMF exposure in Japanese children was lower than that reported in studies in Europe. The DL signals from mobile phone base stations were the most significant contributors to total exposure, while Wireless LAN and digital TV were only higher at home. The urban residence was consistently associated with increases in the four groups of frequency bands (DL, UL, digital TV, and TDD). TDD level has several associations with mobile phone usage (calls using mobile phones, video viewing, text message service, and online game). The association between inattention/hyperactivity subscale of the Strengths and Difficulties Questionnaire (SDQ) and higher Wireless LAN exposure at nighttime was also noted. Further studies with additional data will shed light on factors involved in RF-EMF exposure among Japanese children.

Keywords:

RF electromagnetic field, exposimeter, children, internet environment, mobile phone usage, epidemiology

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Ethical considerations: The study protocol was approved by the institutional ethics board for epidemiological studies at the Hokkaido University Graduate School of Medicine and Hokkaido University Center for Environment and Health Sciences. Written informed consent was obtained from all participants at the time of enrollment.

1. **Introduction**

The opportunities for exposure to radiofrequency electromagnetic fields (RF-EMF) among children are increasing due to the widespread use and availability of smartphones and Wireless Local Area Network (LAN) in households. Previous studies on exposure among children to RF-EMF investigated the association between RF-EMF and behavioral problems (Calvente et al., 2015; Roser et al., 2016; Schoeni et al., 2016; Thomas et al., 2010b) along with the impact on cognitive ability (Abramson et al., 2009; Calvente et al., 2015; Guxens et al., 2016; Thomas et al., 2010a; Thomas et al., 2010b) of school-aged children. However, the results were inconsistent, likely a result of difficulty in the assessment of exposure and lack of data regarding confounders. Ishihara et al. (2020) reviewed previous studies on RF-EMF and cognitive function, suggesting one of the key conditions for a negative relation between RF-EMF and cognitive performance was detected when using objective measurement (i.e., exposure recording) not subjective measurement (i.e., questionnaire) for RF-EMF assessment.

Several studies objectively measured RF-EMF exposure. In recent years, five epidemiological studies in several countries measured personal exposure to RF-EMF. These are comparable to the present study because the recording devices are of the same exposure meter, ExpoM-RF (Fields At Work, Zurich, Switzerland) (Birks et al., 2018; Choi et al., 2018; Eeftens et al., 2018; Gallastegi et al., 2018; Zeleke et al., 2018). Birks et al. (2018) and Eeftens et al. (2018) reported RF-EMF exposure levels of children and their parents in five European countries; Gallastegi et al. (2018) compared exposure levels by spot and personal measurement in the Spanish Infancia y Medio Ambiente (INMA) birth cohort; Zeleke et al. (2018) analyzed the distribution of RF-EMF exposure by day and time in Melbourne, Australia. Choi et al. (2018) is the only report on RF-EMF exposure from Asia, specifically, Korea. Exposure to Wireless Fidelity or wireless Internet connection (Wi-Fi) band in Mexico and Jordan has been reported (Ramirez-Vazquez et al, 2020; Ramirez-Vazquez et al, 2021), using a personal exposure meter EME SPY 140 (Brest, France). However, comparisons are difficult when different types of equipment are used or when the exposure environment changes over time. To the best of our knowledge, there have been no reports on RF-EMF exposure from Japan, despite the expected differences in the radio wave environment.

Therefore, our study assessed RF-EMF exposure using personal recording through exposure meter and questionnaires to estimate individual exposure levels. Our aim was to explore the RF-EMF exposure in Japanese children and to compare their RF-EMF environmental exposure to that of Europe or other countries. Additionally, we examined the relationship between RF-EMF exposure and children's characteristics, internet environment, and mobile phone usage. Furthermore, whether the children's developmental characteristics (problematic behavior or internet addiction) were associated with RF-EMF exposure was examined. Internet addiction leads to high RF-EMF exposure by nature, and several studies have found an association between attention deficit hyperactivity disorder (ADHD) and internet addiction (Ho et al., 2014; Wang et al., 2017). Therefore, we also investigated the association between RF-EMF exposure level and developmental characteristics; such as behavioral problems including ADHD symptoms and internet addiction. For this study, the data from an ongoing birth cohort study, the Hokkaido study on Environment and Children's Health, were used. This was primarily due to availability of data on confounders, since basic information on mothers-children pairs is collected from in-utero to date.

2. Methods

2.1. Study design and population

This study was based on a prospective birth cohort, the Hokkaido Study on the Environment and Children's Health, the Hokkaido cohort. Details of the study population, data collection, and questionnaire contents have been described previously (Kishi et al., 2021; Kishi et al., 2017; Kishi et al., 2013; Kishi et al., 2011). Native Japanese citizens who received antenatal health care during early pregnancy (<13 weeks of gestational age) at any of the 37 hospitals and clinics in Hokkaido Prefecture were eligible for enrollment in this study. In total, 20,926 mother-child pairs were registered in the Hokkaido cohort between 2003 and 2011. Approximately 12,000 pairs are still tracked in the current survey from March 2020.

The recording of RF-EMF was implemented with face-to-face examination of cognitive ability for the children at both 8-10 years and 14-16 years of age. Invitation letters were sent to 705 children who could be followed up and were living close to Sapporo city where the face-to-face examination was held. A total of 107 mother-child pairs agreed to participate in RF-EMF recordings and questionnaire surveys. We also conducted a face-to-face examination of cognitive ability for further analysis. These results are presented separately.

This study was conducted in accordance with the tenets underlying the Declaration of Helsinki, and the protocol was approved by the institutional ethics board for epidemiological studies at the Hokkaido University Graduate School of Medicine and Hokkaido University Center for Environment and Health Sciences. Written informed consent was obtained from all participants at the time of enrollment.

2.2. Personal RF-EMF exposure recording and analysis

Personal RF-EMF exposure was recorded using personal portable exposure meters or "exposimeters" (ExpoM-RF Japanese version [Fields At Work, Zurich, Switzerland]) (Fields at Work - Products

[Internet], 2016) between March 2020 and April 2021. The exposure meters were adjusted to the frequency bands used in Japan and calibrated by the manufacturer in Switzerland in 2020. The exposure meters used in this study measured personal environmental exposure to 16 different frequency bands, which were 700 MHz Frequency Division Duplex (FDD) UL, 700 MHz FDD DL, digital TV, 800 MHz FDD UL, 800 MHz FDD DL, 900 MHz FDD UL, 900 MHz FDD DL, 1.5 GHz FDD DL, 1.7 GHz FDD UL, 1.9 GHz Time Division Duplex (TDD), 2.1 GHz FDD UL, 2.1 GHz FDD DL, ISM 2.4 GHz TDD, 2.5 GHz TDD, 3.5 GHz TDD, ISM 5.8 GHz TDD, as shown in Table 1. A measurement sampling interval was 10 seconds.

After face-to-face examination of cognitive ability, participants wore a nylon bag with a metal zipper containing an exposure meter and recorded RF-EMF for 3 days. They wore the bag around their waist when possible, during the day, while some older children carried the device in a backpack. Participants were instructed to hold the exposure meter facing a specific direction (the surface of the device was outward) and not to allow the device to be in direct contact with their mobile phones. During the measurement period, children were instructed to behave as they normally would and to document the place of recording (such as home, school, outdoors, indoors other than home or school, or commuting).

2.3. Questionnaire

In addition to RF-EMF recording, we collected information about RF-EMF exposure, outcome, and confounders using a questionnaire. The information on the internet environment at home and mobile phone usage was collected from parents and children. To analyze the association to RF-EMF exposure, the use of mobile phones and wireless communication devices (talking, internet, game, among others), internet environment in the home, lifestyle, and the residential area were included in the questionnaires. The Strengths and Difficulties Questionnaire (SDQ) was completed by parents. The SDQ is one of the common instruments for assessing behavior and mental health problems among children and adolescents aged 2–17 years. The SDQ consists of 25 items, each rated as being not true (0), somewhat true (1), or certainly true (2). The items are divided into five subscales covering conduct problems, hyperactivity, emotional symptoms, peer problems, and prosocial behavior (Goodman, 2001). Summing up the scores on the four subscales excluding prosocial behavior generates the SDQ total difficulties score (TDS), ranging from 0 to 40. Cut-off TDS from the SDQ Japanese version of 12/13 for normal/borderline and 15/16 for borderline/high have been validated previously (Matsuishi et al., 2008). In this study, children were divided into two groups, with normal or borderline/high TDS scores, and five subscales. The cut-off score of the five subscales, conduct problems, hyperactivity, emotional symptoms, peer problems, and prosocial behavior, were 3/4, 5/6, 3/4, 3/4, and 6/5 for normal or borderline/high, respectively (Goodman, 2001). Internet addiction was measured using a questionnaire composed of eleven questions developed by Tobe et al. (2010).

2.4. Statistical analysis

Participants who did not complete at least 30% of data collection for the 3 days (3 d × 24 h × 60 min × 60 s / sampling interval 10 s = 25920 data points) were not included in further analysis. The quantification limits of the exposure meters specified by the developer are shown in Table 1. The values above the upper limit (5 V/m) were censored, and values below two times of the noise level for each device and each frequency were replaced with zero values. The percentages of data points replaced by zero value among recorded time points for individual participants are summarized in Table S1. The output data of the exposure meter were recorded in electric field strength (V/m), but for analysis, all exposure data were converted to power density ($\mu W/m^2$). All data points during the recording period were averaged for each frequency band and each participant. Data on 16 frequency bands were then summarized in six groups of frequency bands as shown in Table 1: downlink from mobile phone base station (DL), uplink from mobile phones to base station (UL), Wireless LAN, terrestrial digital TV broadcasting (digital TV), 1.9 GHz TDD, and total value. Total value was the summation of all measured frequency bands (not weighted by the values in the radio wave protection guidelines in Japan for each frequency band). These exposure levels were stratified for daytime (6 am-10 pm) and nighttime (10 pm-6 am), and for each microenvironment (home, school, outside, indoor, or commuting). Additionally, the contribution (%) of each group of frequency bands to the total exposure of six general bands was calculated as medians of the whole exposure for 3 days. The associations of individual characteristics, internet environment, and mobile phone usage with logarithmic expression of the RF-EMF exposure (dB $\mu W/m^2$) were estimated using multiple regression models adjusted by children's sex, age, and family income. We performed these statistical analyses using SPSS (Version 22.0; SPSS, Chicago, IL, USA).

3. Results

3.1. Characteristics of participants and questionnaire results

A total of 107 children recorded RF-EMF and 101 had valid measurements for the entire measurement period. Table 2 shows the characteristics of participants and questionnaire results. Of all participants, 56.4% were male and the mean age was 11.5±1.6 years. Maternal and paternal ages were 43.8±5.1 and 43.9±10.5 years, respectively. More than half of the parents had >13 years of education and nearly half of the families had an annual income of >5 million yen. The questionnaire results showed that most households had an internet environment (95.0%) and the method to access the internet was wireless (94.1%). The average number of mobile phones in households was 3.4±1.2. Most children used the internet, but parents did limit usage. For the type and structure of the house, which is hypothesized to relate to the ease of penetration of radio waves, the majority of participants had detached houses and houses made from wood. A total of 61.4 % reported having their own mobile phone. As for mobile phone usage, percentages of children who used each mobile phone for more than zero minutes were Internet search (43.6 % on Weekdays and 41.6 % on Weekends/holidays), calling via mobile line (37.6 % on Weekdays and 34.7 % on Weekends/holidays), and calling via an internet protocol (33.7 % on Weekdays and 26.7 % on Weekends/holidays) higher than for other usages such as video viewing, text message service, streaming audio, online game or social networking service.

For child development, the number of participants whose total SDQ score was beyond the cut-off was 16 (15.8%). Mean internet addiction score was 34.0±7.2.

3.2. RF-EMF exposure

The frequency bands and parameters of the RF-EMF exposure levels measured are summarized in Table 1. Given the large variance during the measurement period, the median values were used to represent the RF-EMF exposure levels in the groups of frequency bands (DL, UL, Wireless LAN, digital TV, 1.9 GHz TDD, and total value) stratified for daytime or nighttime, and for each microenvironment (home, school, outside, indoor, or commuting). Table 3 shows the exposure levels during the daytime, nighttime, and entire day. The median Total exposure was 5.5×10 μW/m^2 in the daytime, 2.0×10 μW/m^2 in the nighttime, and 4.3×10 μW/m^2 in sum of the day and nighttime for 3 days. As for the microenvironments, the total exposure was highest when outside (1.4×10^2 μW/m^2), followed by commuting (1.2×10^2 μW/m^2), and when indoors (7.4×10 μW/m^2). The exposure level of 1.9 GHz, which was used in the personal handy-phone system (PHS) until January 2021 in Japan, was extremely low compared to other frequency bands. Figure 1 shows the contribution of each band to the total exposure level in each microenvironment. Overall, the exposure to DL contributed the most to the total exposure in all microenvironments. Wireless LAN and digital TV contributed the highest levels at home among the microenvironments. The 1.9 GHz band contributed very little in all microenvironments. Therefore, subsequent analysis was conducted for the five common frequency bands excluding the 1.9 GHz band.

3.3. RF-EMF exposure and related factors

Table 4 shows associations between characteristics of participants and exposure levels in the daytime and nighttime. The TDD levels of exposure were high among girls than boys (0.203 higher in logarithmic expression of the RF-EMF exposure [dBμV/m^2]). The associations between children's age and digital TV exposure were also significant in the daytime. As for nighttime, there were significant associations between children's age and digital TV exposure, and between paternal education and TDD exposure.

Table 5 shows the associations between daytime exposure and factors that may influence children's RF-EMF exposure, including the internet environment, mobile phone use, and developmental characteristics. Regarding the internet environment, the number of mobile phones at home was associated with increasing UL and TDD levels (geometric mean ratio 0.117, 95% confidence interval (CI) 0.003-0.230 for UL, 0.118, 0.017-0.218 for TDD). The type of house, apartment complex compared to a detached house, was also associated with higher levels of both DL and TDD exposure levels, respectively (0.201, 0.009-0.393 for DL, 0.358, 0.143-0.574 for TDD). Urban areas of residence were associated with higher levels in the four frequency bands levels except for Wireless LAN (0.292, 0.067-0.517 for DL, 0.345, 0.044-0.647 for UL, 0.360, 0.088-0.631 for digital TV, and 0.559, 0.312-0.806 for TDD) than rural area of residence. There was a significant association between the use of cordless phones and TDD levels (-0.299, -0.566 -0.032) and whether the children had their own phones and TDD level (0.232, 0.017-0.447). In relation to mobile phone usage, exposure to TDD band was associated with calls using a mobile phone (0.239, 0.015-0.463 on Weekdays, 0.248, 0.024-0.473 on Weekends/holidays), video viewing (0.342, 0.105-0.579 on Weekdays, 0.260, 0.019-0.501 on Weekends/holidays), text message service (0.284, 0.012-0.556 on Weekdays, 0.429, 0.097-0.761 on Weekends/holidays), and online game using (0.285, 0.015-0.554 on Weekdays). Wireless LAN was associated with Video viewing (0.279, 0.008-0.550 on Weekdays) and online game using (0.314, 0.019-0.610 on Weekends/holidays). Association between DL bands and Text message service (0.426, 0.148-0.704 on Weekends/holidays) and Digital TV bands and video viewing (0.270, 0.024-0.516 on Weekends/holidays), streaming audio using a mobile phone (0.279, 0.031-0.526 on Weekdays, 0.285, 0.049-0.521 on Weekends/holidays) was also significant.

Table 6 shows the associations with nighttime exposure. With respect to internet environment, there were significant associations between the area of residence and DL (0.504, 0.092-0.915). TDD exposure was associated with video viewing (0.617, 0.072-1.163 on Weekdays) and streaming audio (0.549, 0.010-1.089 on Weekends/holidays). The association between text message service and DL (0.617, 0.107-1.127 on Weekends/holidays), online games and Wireless LAN was also significant

(0.495, 0.031-0.960 on Weekends/holidays). Finally, high hyperactivity /inattention scores for the SDQ in children's developmental characteristics were associated with higher Wireless LAN usage levels (0.737, 0.191-1.283). These results indicate that individuals with hyperactivity/inattention-related problems are exposed to more Wireless LAN frequency bands.

4. Discussion

4.1. Summary of results

The present study aimed to explore children's exposure to RF-EMF in Japan using the objective method. Children in the Hokkaido cohort recorded personal RF-EMF exposure using the exposure meter and reported the microenvironment during recording. Parents answered the questionnaires on internet environment, mobile phone usage, and child developmental status. The RF-EMF exposure was higher during daytime than nighttime, and DL from mobile phone base stations had the most significant contributions to total exposure. Among the microenvironments, outdoors had the highest exposure followed by commuting. Several factors among the internet environments, mobile phone usage, and developmental characteristics were associated with the RF-EMF levels.

4.2. RF-EMF exposure levels

The median of the total RF-EMF exposure was 55.3 $\mu W/m^2$ for the whole day, 43.3 $\mu W/^2$ for daytime, and 20.2 $\mu W/m^2$ for nighttime. It is difficult to compare the exposure levels to those reported in previous studies because of the difference in RF-EMF bands used in each country, and this study does not include exposure at FM radio frequencies. Birks et al. (2018) showed that broadcast, which was largely composed of FM radio frequency band, was the second largest contributor to exposure in Europe. Additionally, conclusions from the previous personal surveys about exposure patterns have become outdated due to rapidly evolving mobile technologies and functionalities. The recording period was 2014-2017 in previous studies and 2020-2021 in the present study. According to a study by the Cabinet Office Japan, the percentage of elementary school students using the internet via smartphones increased from 23.3% in 2017 to 53.1% in 2020, suggesting that the internet environment around children can change considerably even within 3 years (Cabinet Office of Japan, 2022). Table 7 shows the most recent survey studies on personal exposure. The total exposure level in the present study was lower than the 75.5 μW/m^2 in five countries in Europe (Birks et al., 2017), 114.8 μW/m^2 in Melbourne, Australia (Zeleke et al., 2018), 52.13 μW/m^2 in Basque Country, Spain (Gallastegi et al., 2018), but higher than the 26.17 μW/m^2 in children in Seoul, Cheonan, and Ulsan (Choi et al., 2018). These results were also consistent with Onishi et al. (2021), who reported lower EMF area exposure levels in outdoor environments in Japan than those in the UK. The total exposure may have been underestimated in this study because the levels of exposure to FM radio frequencies were not collected, but the results of our preliminary study have shown that FM radio contributed little to total exposure in Japan (data not shown).

Overall, the patterns of exposure by daytime/nighttime and microenvironments were consistent with results from previous studies. Several previous studies from the Netherlands (Bolte and Eikelboom, 2012) and Switzerland (Frei et al., 2009; Roser et al., 2017) also found that RF-EMF exposure level was typically lower during the nighttime than during the daytime. Regarding microenvironments, RF exposure from outdoor environmental sources was higher when outdoors than indoors, similar to findings of other studies (Birks et al., 2018; Gallastegi et al., 2018; Joseph et al., 2010; Verloock et al., 2014). The exposure levels for DL, digital TV from outdoor environmental sources (e.g. base station) were higher outside, and that in Wireless LAN was higher in the home. Regarding the contribution of each band to the total exposure level, the exposure to the DL contributed the most to the total exposure in all microenvironments. The exposure levels of the Wireless LAN and digital TV were the most dominant at home, while the 1.9 GHz band, the frequency band once used for PHS, was rarely recorded as it was no longer used in the study area.

4.3. RF-EMF exposure and related factors

The associations between the RF-EMF exposure levels and various factors in the internet environment, mobile phone usage, and developmental characteristics were observed mainly during the daytime rather than nighttime. During the daytime, the condition of the residence area was consistently associated with the exposure levels of the DL, UL, digital TV, and TDD band. Considering previous studies (Bolte and Eikelboom, 2012; Thomas et al., 2008a; Thomas et al., 2008b), the urban residence is the most important factor to determine the higher EM-REF exposure level. TDD level has several associations with mobile phone usage (calls using mobile phones, video viewing, text message service, and online game). Participants might often use these contents during the daytime using a mobile phone without the use of wireless LAN. The level of TDD may be related to the behavioral tendencies of the participants and their use of cell phones such that they are willing to use the latest technology, TDD. The association between RF-EMF exposure levels for digital TV and streaming audio is hard to explain but given that music is listened to in transit or while walking, residential area, or time spent outside may be a confounding factor. The “number of mobile phones in the home” and “area of residence” might be crucial factors for RF-EMF exposure from mobile phones, because these factors are associated with both UL and TDD which include the uplink signal from mobile phones. On the other hand, “type of house”, “area of residence”, use of text message” might be measures of the exposure from mobile base stations, as these are associated with both DL and TDD including the downlink signal from mobile phone base stations.

During the nighttime, there were several single associations between the RF-EMF exposure and the internet environment factor or mobile phone usage. It is possible that many children used their digital devices less from 10 pm to 6 am than they did during the day. Interestingly, Wireless LAN levels at nighttime were significantly higher among those with high hyperactivity/inattention scores of SDQ, one of the common symptoms of ADHD, than those with low scores. Although the association between ADHD symptoms and internet addiction has been reported (Ho et al., 2014; Wang et al., 2017; Yen et al., 2009), there was no relationship between internet addiction and RF-EMF exposure in the present study. Tateno et al. (2016) suggested that ADHD traits, such as impulsivity, could be related to difficulty in controlling internet use and online gaming. Therefore, the exposure to Wireless LAN recorded by the exposure meter might increase for those who could not limit the use of wireless electrical devices (mobile phones, gaming devices, among others) at nighttime because of impulsivity, rather than internet addiction.

4.4. Strengths and limitations of the study

The present study is the first to examine personal RF-EMF exposure in Japan. The strength of this study was in measuring the actual daily RF-EMF exposure of Japanese children using the exposure meter as an objective indicator. Additionally, we were able to obtain insight into the association between children's developmental characteristics and RF-EMF exposure. One of the limitations of the present study is that the causal relationship was not determined because of the cross-sectional design. Further, there may be mixed effects of season and COVID-19 on children's lives during the study period, for approximately 1 year. This is observed in the relatively large variation in the amount of time children spend using mobile phones and being outside. From 2020 to date, we have collected additional exposure data and performed in-person inspections, and these data will allow for prospective analysis and to resolve seasonal problems in the future. Another limitation is regarding the recording device, ExpoM- RF. Although all participants were instructed to wear the device in the same location, body shielding and reflection from the body leading to problems during recording are inevitable (Yamamoto et al., 2022). General problems of personal exposure surveys using ExpoM-RF are discussed in the supplemental material of Birks et al. (2018). Nevertheless, the present study is the first to describe Japanese children's RF-EMF exposure and its relation to the internet environment, mobile phone usage, and developmental characteristics. Further studies should consider better recording devices, including devices with the ability to record 5G exposure.

5. Conclusion

We recorded children's personal RF-EMF exposures using the exposure meter and examined related factors for their exposure. The personal RF-EMF exposure in Japanese children was lower than that reported in previous European studies. Downlink from mobile phone base stations was the most significant contributor to the total exposure, while Wireless LAN and digital TV were higher at home than in other microenvironments. There were several significant associations between internet environment and mobile phone usage and exposure level in the daytime analysis. Among them, the urban residence and related characteristics were consistently associated with higher levels of DL, UL, digital TV, and TDD band. At nighttime, the association between the inattention/hyperactivity subscale of SDQ and Wireless LAN exposure was found in addition to associations between the internet environment or mobile phone usage and the RF-EMF exposure. Further studies with additional data and robust study designs are required to explore the most possible factors involved in RF-EMF exposure among Japanese children.

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Declarations

Competing interests: The authors have no actual or potential conflicts of interest to declare.

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References

Abramson, M.J., Benke, G.P., Dimitriadis, C., Inyang, I.O., Sim, M.R., Wolfe, R.S., Croft, R.J.,

2009. Mobile telephone use is associated with changes in cognitive function in young adolescents. Bioelectromagnetics. 30, 678–686.

Birks, L., Guxens, M., Papadopoulou, E., Alexander, J., Ballester, F., Estarlich, M., Gallastegi, M., Ha, M., Haugen, M., Huss, A., Kheifets, L., Lim, H., Olsen, J., Santa-Marina, L., Sudan, M., Vermeulen, R., Vrijkotte, T., Cardis, E., Vrijheid, M., 2017. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. Environ. Int. 104, 122–131.

Birks, L.E., Struchen, B., Eeftens, M., van Wel, L., Huss, A., Gajšek, P., Kheifets, L., Gallastegi, M., Dalmau-Bueno, A., Estarlich, M., Fernandez, M.F., Meder, I.K., Ferrero, A., Jiménez-Zabala, A., Torrent, M., Vrijkotte, T.G.M., Cardis, E., Olsen, J., Valič, B., Vermeulen, R., Vrijheid, M., Röösli, M., Guxens, M., 2018. Spatial and temporal variability of personal environmental exposure to radio frequency electromagnetic fields in children in Europe. Environ. Int. 117, 204–214.

Bolte, J.F., Eikelboom, T., 2012. Personal radiofrequency electromagnetic field measurements in the Netherlands: exposure level and variability for everyday activities, times of day and types of area. Environ. Int. 48, 133–142.

Cabinet Office of Japan, 2022. https://www8.cao.go.jp/youth/youth-harm/chousa/net-jittai_list.html. (Accessed 2022.3.28).

Calvente, I., Fernández, M.F., Pérez-Lobato, R., Dávila-Arias, C., Ocón, O., Ramos, R., Ríos-Arrabal, S., Villalba-Moreno, J., Olea, N., Núñez, M.I., 2015. Outdoor characterization of radio frequency electromagnetic fields in a Spanish birth cohort. Environ. Res. 138, 136–143.

Choi, J., Hwang, J.H., Lim, H., Joo, H., Yang, H.S., Lee, Y.H., Eeftens, M., Struchen, B., Röösli, M., Lee, A.K., Choi, H.D., Kwon, J.H., Ha, M., 2018. Assessment of radiofrequency electromagnetic field exposure from personal measurements considering the body shadowing effect in Korean children and parents. Sci. Total Environ. 627, 1544–1551.

Eeftens, M., Struchen, B., Birks, L.E., Cardis, E., Estarlich, M., Fernandez, M.F., Gajšek, P., Gallastegi, M., Huss, A., Kheifets, L., Meder, I.K., Olsen, J., Torrent, M., Trček, T., Valič, B., Vermeulen, R., Vrijheid, M., van Wel, L., Guxens, M., Röösli, M., 2018. Personal exposure to radio-frequency electromagnetic fields in Europe: is there a generation gap? Environ. Int. 121, 216–226.

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.

Gallastegi, M., Huss, A., Santa-Marina, L., Aurrekoetxea, J.J., Guxens, M., Birks, L.E., Ibarluzea, J., Guerra, D., Röösli, M., Jiménez-Zabala, A., 2018. Children’s exposure assessment of radiofrequency fields: comparison between spot and personal measurements. Environ. Int. 118, 60–69.

Goodman, R., 2001. Psychometric properties of the strengths and difficulties questionnaire. J. Am. Acad. Child Adolesc. Psychiatry. 40, 1337–1345.

Guxens, M., Vermeulen, R., van Eijsden, M., Beekhuizen, J., Vrijkotte, T.G.M., van Strien, R.T., Kromhout, H., Huss, A., 2016. Outdoor and indoor sources of residential radiofrequency electromagnetic fields, personal cell phone and cordless phone use, and cognitive function in 5–6 years old children. Environ. Res. 150, 364–374.

Ho, R.C., Zhang, M.W., Tsang, T.Y., Toh, A.H., Pan, F., Lu, Y., Cheng, C., Yip, P.S., Lam, L.T., Lai, C.M., Watanabe, H., Mak, K.K., 2014. The association between internet addiction and psychiatric co-morbidity: a meta-analysis. BMC Psychiatry. 14, 183.

Ishihara, T., Yamazaki, K., Araki, A., Teraoka, Y., Tamura, N., Hikage, T., Omiya, M., Mizuta, M., Kishi, R., 2020. Exposure to radiofrequency electromagnetic field in the high-frequency band and cognitive function in children and adolescents: A literature review. Int. J. Environ. Res. Public Health. 17.

Joseph, W., Frei, P., Roösli, M., Thuróczy, G., Gajsek, P., Trcek, T., Bolte, J., Vermeeren, G., Mohler, E., Juhász, P., Finta, V., Martens, L., 2010. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. Environ. Res. 110, 658–663.

Kishi, R., Araki, A., Minatoya, M., Hanaoka, T., Miyashita, C., Itoh, S., Kobayashi, S., Ait Bamai, Y., Yamazaki, K., Miura, R., Tamura, N., Ito, K., Goudarzi, H., members of The Hokkaido Study on, E., & Children's, H. (2017, May 18). The Hokkaido Birth Cohort Study on Environment and Children's Health: cohort profile-updated 2017. Environ Health Prev Med, 22(1), 46. https://doi.org/10.1186/s12199-017-0654-3

Kishi, R., Ikeda-Araki, A., Miyashita, C., Itoh, S., Kobayashi, S., Ait Bamai, Y., Yamazaki, K., Tamura, N., Minatoya, M., Ketema, R. M., Poudel, K., Miura, R., Masuda, H., Itoh, M., Yamaguchi, T., Fukunaga, H., Ito, K., Goudarzi, H., members of The Hokkaido Study on, E., & Children's, H. (2021, May 22). Hokkaido birth cohort study on environment and children's health: cohort profile 2021. Environ Health Prev Med, 26(1), 59. https://doi.org/10.1186/s12199-021-00980-y

Kishi, R., Kobayashi, S., Ikeno, T., Araki, A., Miyashita, C., Itoh, S., Sasaki, S., Okada, E., Kobayashi, S., Kashino, I., Itoh, K., Nakajima, S., Members of the Hokkaido Study on, E., & Children's, H. (2013, Nov). Ten years of progress in the Hokkaido birth cohort study on environment and children's health: cohort profile--updated 2013. Environ Health Prev Med, 18(6), 429-450. https://doi.org/10.1007/s12199-013-0357-3

Kishi, R., Sasaki, S., Yoshioka, E., Yuasa, M., Sata, F., Saijo, Y., Kurahashi, N., Tamaki, J., Endo, T., Sengoku, K., Nonomura, K., Minakami, H., Hokkaido Study on, E., & Children's, H. (2011, Jun). Cohort profile: the Hokkaido study on environment and children's health in Japan. Int J Epidemiol, 40(3), 611-618. https://doi.org/10.1093/ije/dyq071

Matsuishi, T., Nagano, M., Araki, Y., Tanaka, Y., Iwasaki, M., Yamashita, Y., Nagamitsu, S., Iizuka, C., Ohya, T., Shibuya, K., Hara, M., Matsuda, K., Tsuda, A., Kakuma, T., 2008. Scale properties of the Japanese version of the Strengths and Difficulties Questionnaire (SDQ): a study of infant and school children in community samples. Brain Dev. 30, 410–415.

Onishi, T., Ikuyo, M., Tobita, K., Liu, S., Taki, M., Watanabe, S., 2021. Radiofrequency exposure levels from mobile phone base stations in outdoor environments and an underground shopping mall in Japan. Int. J. Environ. Res. Public Health. 18.

Ramirez-Vazquez, R., Arabasi, S., Al-Taani, H., Sbeih, S., Gonzalez-Rubio, J., Escobar, I., & Arribas, E. (2020). Georeferencing of personal exposure to radiofrequency electromagnetic fields from Wi-fi in a university area. International Journal of Environmental Research and Public Health, 17(6), 1898.

Ramirez-Vazquez, R., Gonzalez-Rubio, J., Escobar, I., Suarez Rodriguez, C. D. P., & Arribas, E. (2021). Personal exposure assessment to Wi-Fi radiofrequency electromagnetic fields in Mexican microenvironments. International Journal of Environmental Research and Public Health, 18(4), 1857.

Roser, K., Schoeni, A., Röösli, M., 2016. Mobile phone use, behavioural problems and concentration capacity in adolescents: A prospective study. Int. J. Hyg. Environ. Health. 219, 759–769.

Roser, K., Schoeni, A., Struchen, B., Zahner, M., Eeftens, M., Fröhlich, J., Röösli, M., 2017. Personal radiofrequency electromagnetic field exposure measurements in Swiss adolescents. Environ. Int. 99, 303–314.

Schoeni, A., Roser, K., Bürgi, A., Röösli, M., 2016. Symptoms in Swiss adolescents in relation to exposure from fixed site transmitters: a prospective cohort study. Environ. Health. 15, 77.

Tateno, M., Teo, A.R., Shirasaka, T., Tayama, M., Watabe, M., Kato, T.A., 2016. Internet addiction and self-evaluated attention-deficit hyperactivity disorder traits among Japanese college students. Psychiatry Clin. Neurosci. 70, 567–572.

Thomas, S., Benke, G., Dimitriadis, C., Inyang, I., Sim, M.R., Wolfe, R., Croft, R.J., Abramson, M.J., 2010a. Use of mobile phones and changes in cognitive function in adolescents. Occup. Environ. Med. 67, 861–866.

Thomas, S., Heinrich, S., von Kries, R., Radon, K., 2010b. Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents. Eur. J. Epidemiol. 25, 135–141.

Thomas, S., Kühnlein, A., Heinrich, S., Praml, G., Nowak, D., von Kries, R., Radon, K., 2008a. Personal exposure to mobile phone frequencies and well-being in adults: a cross-sectional study based on dosimetry. Bioelectromagnetics. 29, 463–470.

Thomas, S., Kühnlein, A., Heinrich, S., Praml, G., von Kries, R., Radon, K., 2008b. Exposure to mobile telecommunication networks assessed using personal dosimetry and well-being in children and adolescents: the German MobilEe-study. Environ. Health. 7, 54.

Tobe, H., Takeuchi, K., Hotta, M., 2010. The relationship between the tendency toward Internet dependence and mental health and the psychosocial problems of students. Jpn. J. Sch. Health. 52, 125–134.

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

Wang, B.Q., Yao, N.Q., Zhou, X., Liu, J., Lv, Z.T., 2017. The association between attention deficit/hyperactivity disorder and internet addiction: a systematic review and meta-analysis. BMC Psychiatry. 17, 260.

Yamamoto, K., Ozaki, R., Hikage, T., Yamazaki, K., Miyashita, C., Kishi, R., 2022. Human body blockage characteristics estimation on personal exposure meter for epidemiologic research on RF exposure and adolescent health. The J. Inst. Electron. Inf. Comm. Eng.

Yen, J.Y., Yen, C.F., Chen, C.S., Tang, T.C., Ko, C.H., 2009. The association between adult ADHD symptoms and internet addiction among college students: the gender difference. Cyberpsychol. Behav. 12, 187–191.

Zeleke, B.M., Brzozek, C., Bhatt, C.R., Abramson, M.J., Croft, R.J., Freudenstein, F., Wiedemann, P., Benke, G., 2018. Personal exposure to radio frequency electromagnetic fields among Australian adults. Int. J. Environ. Res. Public Health. 15.

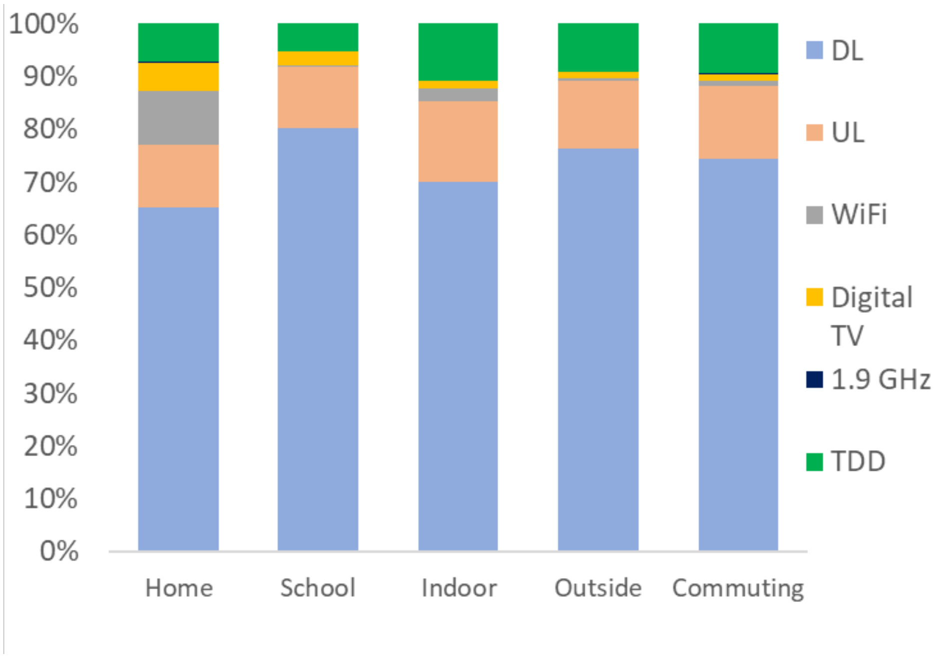

Figure 1. Contributions (%) of each group of frequency bands to total exposure in each microenvironment DL, Downlink; UL, Uplink; TDD, Time Division Duplex.

Table 1 Frequency bands captured by personal exposure meters

Band name	Frequency			Typical dynamic range			usage	Classification
Digital TV	470 -	710	MHz	0.005 -	5	V/m	Digital TV	Digital TV
700 MHz FDD UL	718 -	748	MHz	0.005 -	5	V/m	Mobile phone	UL
700 MHz FDD DL	773 -	803	MHz	0.02 -	5	V/m	Mobile phone	DL
800 MHz FDD UL	814 -	849	MHz	0.005 -	5	V/m	Mobile phone	UL
800 MHz FDD DL	859 -	894	MHz	0.005 -	5	V/m	Mobile phone	DL
900 MHz FDD UL	880 -	915	MHz	0.005 -	5	V/m	Mobile phone	UL
900 MHz FDD DL	925 -	960	MHz	0.005 -	5	V/m	Mobile phone	DL
1.5 GHz FDD DL	1475.9 -	1510.9	MHz	0.005 -	5	V/m	Mobile phone	DL
1.7 GHz FDD UL	1710 -	1785	MHz	0.005 -	5	V/m	Mobile phone	UL
1.9GHz TDD	1884.5 -	1915.7	MHz	0.005 -	5	V/m	PHS & DECT	1.9GHz TDD
2.1 GHz FDD UL	1920 -	1980	MHz	0.003 -	5	V/m	Mobile phone	UL
2.1 GHz FDD DL	2110 -	2170	MHz	0.003 -	5	V/m	Mobile phone	DL
ISM 2.4 GHz	2400 -	2497	MHz	0.003 -	5	V/m	Wireless LAN	WiFi
2.5GHz TDD	2545 -	2645	MHz	0.003 -	5	V/m	Mobile phone	TDD
3.5GHz TDD	3.5		GHz	0.003 -	5	V/m	Mobile phone	TDD
ISM 5.8 GHz	5.8		GHz	0.05 -	5	V/m	Wireless LAN	WiFi

FDD: frequency division duplex, TDD: time division duplex, DL: downlink, UL: uplink, PHS: personal handy-phone system, ISM: ISM: Industrial Scientific and Medical Band

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Table 2. Characteristics of the participants (n=101) and summary of the questionnaire

Characteristics & Results of Questionnaire		Mean±SD No.(%)	
Characteristics			
Children			
Sex	Male	57	(56.4)
	Female	44	(43.6)
Age		11.5	±1.57
Maternal			
Age		43.8	±5.13
Education ≥ 13 years		67	(66.3)
Paternal			
Age		43.9	±10.5
Education ≥ 13 years		53	(52.5)
Family			
annual income ≥ 5 million yen		48	(47.5)
Questionnaire			
Internet environment at the home			
Internet environment	yes	96	(95.0)
Wireless Internet	yes	95	(94.1)
Number of access point		1.1	±0.45
Number of mobile phone		3.4	±1.2
Children's internet usage			
Internet use	yes	99	(98.0)
Limitation of Internet use for children			
Weekday	yes	71	(70.3)
Weekend/hoidays	yes	65	(64.4)
Residence			
Type of house	Detached house	64	(63.4)
	Apartment complex	35	(34.7)
The house structure	Wood	65	(64.4)
	Reinforced concrete	34	(33.7)
Area of residence	Rural	22	(21.8)
	Urban	79	(78.2)
Use of electrical device in their home			
Use of cordless phone	yes	20	(19.8)
Use of wearable devices	yes	19	(18.8)
Children have their own mobile phones	yes	62	(61.4)
Usage of mobile phones			
Calling via mobile line			
Weekday	yes	38	(37.6)
Weekend/hoidays	yes	35	(34.7)
Calling via internet protocol			
Weekday	yes	34	(33.7)
Weekend/hoidays	yes	27	(26.7)
Video viewing			
Weekday	yes	29	(28.7)
Weekend/hoidays	yes	32	(31.7)
Internet search			
Weekday	yes	44	(43.6)
Weekend/hoidays	yes	42	(41.6)
Text message service via mobile line			
Weekday	yes	24	(23.8)
Weekend/hoidays	yes	15	(14.9)
Streaming audio			
Weekday	yes	31	(30.7)

Weekend/hoidays	yes	32	(31.7)
Online game			
Weekday	yes	19	(18.8)
Weekend/hoidays	yes	22	(21.8)
Social networking service			
Weekday	yes	13	(12.9)
Weekend/hoidays	yes	13	(12.9)
Children's developmental characteristics			
SDQ (Number of borderline/high group)			
Total score		16	(15.8)
Conduct problems		10	(9.9)
Hyperactivity/Inattention		12	(11.9)
Emotional Symptoms		24	(23.8)
Peer problems		10	(9.9)
Prosocial Behavior		30	(29.7)
Internet addiction tendency score		34.0	±7.2

SDQ: Strength and Difficulties Questionnaire

Table3 Exposure level during daytime, nighttime, and whole the day(μW/m^2).

	Mean	±SD	Min	Median	95%tile	Max	GM
Diurnal							
All day							
Total	10.0×10^2	$\pm1.6\times10^2$	5.0	4.3×10	4.1×10^2	1.1×10^3	5.4×10
DL	0.5×10^2	$\pm0.6\times10^2$	2.1	2.7×10	1.9×10^2	4.1×10^2	2.8×10
UL	0.2×10^2	$\pm0.9\times10^2$	2.1×10^{-1}	5.5	5.9×10	7.5×10^2	6.0
Wireless LAN	0.1×10^2	$\pm0.4\times10^2$	9.2×10^{-2}	2.4	2.2×10	4.0×10^2	2.8
Digital TV	0.1×10^2	$\pm0.4\times10^2$	4.7×10^{-2}	1.5	1.5×10	3.9×10^2	1.6
1.9 GHz	0.3×10	$\pm2.1\times10$	5.3×10^{-5}	2.5×10^{-2}	9.8×10^{-1}	1.8×10^2	2.7×10^{-2}
TDD	0.1×10^2	$\pm0.1\times10^2$	1.1×10^{-1}	2.7	1.6×10	5.8×10	2.5
Daytime							
Total	0.9×10^2	$\pm1.0\times10^2$	5.4	5.5×10	3.1×10^2	5.9×10^2	6.1×10
DL	0.5×10^2	$\pm0.6\times10^2$	2.3	3.6×10	2.0×10^2	2.9×10^2	3.3×10
UL	0.2×10^2	$\pm0.6\times10^2$	3.0×10^{-1}	7.1	6.5×10	5.4×10^2	6.9
Wireless LAN	0.1×10^2	$\pm0.5\times10^2$	1.2×10^{-1}	3.1	2.4×10	4.6×10^2	3.4
Digital TV	0.3×10	$\pm0.6\times10$	3.5×10^{-2}	1.6	9.1	4.7×10	1.4
1.9 GHz	0.3	±0.9	7.9×10^{-5}	2.3×10^{-2}	7.9×10^{-1}	7.4	3.0×10^{-2}
TDD	0.5×10	$\pm0.8\times10$	1.2×10^{-1}	3.4	1.8×10	5.0×10	2.9
Nighttime							
Total	1.0×10^3	$\pm0.3\times10^3$	1.9	2.0×10	4.7×10^2	2.9×10^3	2.3×10
DL	0.4×10^2	$\pm0.9\times10^2$	8.0×10^{-2}	9.3	1.4×10^2	6.4×10^2	9.9
UL	0.3×10^2	$\pm1.7\times10^2$	4.5×10^{-2}	1.2	5.6×10	1.2×10^3	1.8
Wireless LAN	0.6×10	$\pm2.2\times10$	2.5×10^{-3}	6.1×10^{-1}	3.5×10	1.9×10^2	6.7×10^{-1}
Digital TV	0.1×10^2	$\pm1.1\times10^2$	1.1×10^{-3}	1.2	2.0×10	1.1×10^3	1.4
1.9 GHz	0.1×10^2	$\pm0.6\times10^2$	0.0	3.4×10^{-4}	2.5×10^{-1}	5.3×10^2	0.0
TDD	0.05×10^2	$\pm0.16\times10^2$	0.0	7.5×10^{-1}	1.2×10	1.2×10^2	0.0
Microenvironments							
Home							
Total	0.5×10^2	$\pm0.6\times10^2$	3.4	2.2×10	4.4×10^2	3.8×10^2	3.3×10
DL	0.3×10^2	$\pm0.5\times10^2$	7.4×10^{-1}	1.3×10	1.5×10^2	2.7×10^2	1.3×10
UL	0.5×10	$\pm0.6\times10$	2.8×10^{-1}	1.7	5.3×10	3.1×10	2.7
Wireless LAN	5.0×10	$\pm0.7\times10$	1.7×10^{-1}	2.6	2.6×10	2.7×10	3.0
Digital TV	0.3×10	$\pm0.5\times10$	0.0	1.1	1.7×10	2.3×10	1.2
1.9 GHz	0.4×10^{-1}	$\pm0.6\times10^{-1}$	0.0	1.5×10^{-2}	4.4×10^{-1}	2.6×10^{-1}	0.0
TDD	0.04×10^2	$\pm0.12\times10^2$	0.0	1.3	1.4×10	8.7×10	1.1
School							
Total	0.3×10^2	$\pm0.4\times10^2$	3.4×10^{-1}	1.9×10	1.7×10^2	2.3×10^2	2.1×10
DL	0.2×10^2	$\pm0.4\times10^2$	2.0×10^{-2}	1.1×10	1.3×10^2	2.3×10^2	1.3×10
UL	0.4×10	$\pm0.7\times10$	1.6×10^{-1}	1.3	2.8×10	3.1×10	2.0
Wireless LAN	0.05×10	$\pm0.13\times10$	0.0	5.2×10^{-2}	4.1	7.2	7.7×10^{-2}
Digital TV	0.2×10	$\pm0.9\times10$	0.0	4.8×10^{-1}	7.9	6.1×10	4.4×10^{-1}
1.9 GHz	0.04	±0.17	0.0	7.0×10^{-4}	4.4×10^{-1}	1.0	0.0
TDD	0.18×10	$\pm0.24\times10$	0.0	7.6×10^{-1}	9.1	1.1×10	6.6×10^{-1}
Indoor							
Total	0.15×10^3	$\pm0.23\times10^3$	6.7	7.4×10	5.0×10^2	1.5×10^3	7.5×10
DL	0.9×10^2	$\pm1.7\times10^2$	1.0	3.6×10	3.2×10^2	1.1×10^3	0.0
UL	0.4×10^2	$\pm0.9\times10^2$	8.0×10^{-2}	1.0×10	3.4×10^2	4.3×10^2	9.2
Wireless LAN	0.4×10	$\pm0.9\times10$	0.0	1.4	2.0×10	5.3×10	9.1×10^{-1}
Digital TV	0.3×10	$\pm0.5\times10$	0.0	9.7×10^{-1}	1.6×10	3.0×10	0.0
1.9 GHz	0.05×10	$\pm0.10\times10$	0.0	1.1×10^{-1}	4.0	5.6	0.0
TDD	0.1×10^2	$\pm0.3\times10^2$	0.0	6.0	4.3×10	2.1×10^2	0.0
Outside							
Total	0.22×10^3	$\pm0.19\times10^3$	1.4×10	1.4×10^2	6.6×10^2	7.8×10^2	1.4×10^2
DL	0.15×10^3	$\pm0.15\times10^3$	7.5	8.5×10	5.3×10^2	6.4×10^2	9.2×10
UL	0.3×10^2	$\pm0.3\times10^2$	7.7×10^{-1}	1.6×10	1.5×10^2	1.7×10^2	1.5×10
Wireless LAN	0.04×10^2	$\pm0.13\times10^2$	6.0×10^{-2}	5.7×10^{-1}	1.6×10	7.4×10	9.3×10^{-1}

Digital TV	0.5×10	$\pm0.7\times10$	2.1×10^{-1}	1.8	2.1×10	3.8×10	2.1
1.9 GHz	0.03×10^{2}	$\pm0.18\times10^{2}$	0.0	1.2×10^{-2}	2.4	1.3×10^{2}	0.0
TDD	0.3×10^{2}	$\pm0.4\times10^{2}$	1.6×10^{-1}	1.3×10	7.9×10	2.1×10^{2}	1.0×10
While traveling							
Total	0.15×10^{3}	$\pm0.12\times10^{3}$	1.2×10	1.2×10^{2}	5.4×10^{2}	6.2×10^{2}	1.2×10^{2}
DL	0.10×10^{3}	$\pm0.10\times10^{3}$	3.9	7.5×10	3.5×10^{2}	5.7×10^{2}	7.2×10
UL	0.3×10^{2}	$\pm0.4\times10^{2}$	1.9×10^{-1}	1.7×10	1.4×10^{2}	1.9×10^{2}	1.4×10
Wireless LAN	0.4×10	$\pm0.8\times10$	1.0×10^{-2}	1.3	2.1×10	3.4×10	1.5
Digital TV	0.5×10	$\pm1.2\times10$	0.0	1.3	2.7×10	7.8×10	0.0
1.9 GHz	0.07×10	$\pm0.2\times10$	0.0	3.1×10^{-2}	6.8	1.3×10	0.0
TDD	0.13×10^{2}	$\pm0.11\times10^{2}$	1.0×10^{-2}	1.1×10	4.0×10	5.5×10	7.1

DL: Downlink, UL: Uplink, Wireless LAN: Wireless Fidelity, TDD: Time Division Duplex (See also Table 1)

Table 4. Multiple regression analysis of the associations between characteristics of participants and exposure level in day and night time

	DL				UL				Wireless LAN				Digital TV				TDD			
	β	95%			*β*	95%			*β*	95%			*β*	95% CI			*β*	95% CI		
Daytime																				
Children																				
Sex	0.133	(-0.036	,0.302)		0.026	(-0.196	,0.248)		-0.088	(-0.311	,0.134)		0.815	(0.488	,1.361)		**0.203**	**(0.002**	**,0.405)**	*
Age	-0.026	(-0.080	,0.029)		0.012	(-0.059	,0.083)		-0.045	(-0.116	,0.025)		**1.239**	**(1.057**	**,1.449)**	**	0.011	(-0.054	,0.077)	
Maternal																				
Age	-0.005	(-0.022	,0.012)		0.007	(-0.014	,0.029)		0.003	(-0.018	,0.025)		1.023	(0.973	,1.076)		0.001	(-0.019	,0.021)	
Education	0.043	(-0.157	,0.243)		-0.084	(-0.340	,0.173)		-0.224	(-0.475	,0.027)	†	1.050	(0.575	,1.910)		0.132	(-0.106	,0.369)	
Paternal																				
Age	0.002	(-0.007	,0.010)		0.003	(-0.007	,0.014)		0.007	(-0.004	,0.017)		1.009	(0.984	,1.033)		0.001	(-0.009	,0.010)	
Education	0.166	(-0.017	,0.349)	†	-0.045	(-0.286	,0.195)		-0.057	(-0.291	,0.178)		0.759	(0.436	,1.321)		0.127	(-0.094	,0.349)	
Family	0.067	(-0.122	,0.256)		-0.058	(-0.305	,0.190)		0.069	(-0.182	,0.320)		1.194	(0.693	,2.061)		0.141	(-0.081	,0.363)	
Nighttime																				
Children																				
Sex	-0.086	(-0.377	,0.204)		-0.235	(-0.563	,0.093)		-0.070	(-0.424	,0.285)		-0.051	(-0.323	,0.222)		-0.286	(-0.727	,0.155)	
Age	-0.034	(-0.126	,0.058)		-0.010	(-0.115	,0.095)		0.031	(-0.081	,0.144)		**0.103**	**(0.019**	**,0.187)**	*	0.041	(-0.100	,0.181)	
Maternal																				
Age	-0.013	(-0.041	,0.015)		0.002	(-0.030	,0.034)		0.025	(-0.009	,0.059)		0.013	(-0.014	,0.039)		-0.005	(-0.048	,0.038)	
Education	0.041	(-0.296	,0.377)		-0.153	(-0.539	,0.234)		-0.317	(-0.721	,0.087)		-0.141	(-0.461	,0.178)		-0.223	(-0.738	,0.293)	
Paternal																				
Age	0.003	(-0.011	,0.017)		0.008	(-0.008	,0.024)		0.012	(-0.005	,0.029)		0.003	(-0.010	,0.016)		-0.003	(-0.024	,0.018)	
Education	-0.139	(-0.452	,0.174)		-0.226	(-0.584	,0.132)		-0.265	(-0.639	,0.110)		-0.157	(-0.453	,0.139)		**-0.511**	**(-0.986**	**-0.036)**	*
Family	0.155	(-0.184	,0.495)		0.057	(-0.303	,0.417)		-0.116	(-0.504	,0.271)		0.042	(-0.245	,0.328)		0.180	(-0.334	,0.694)	

Regression coefficients (β) and 95% confidence intervals (CIs) for the associations between characteristics and $\log_{10}$-transformed RF-EMF exposure levels as determined by a linear regression model.

Each factor was introduced into the model separately without adjustment factors. ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$

Table 5. Results of multiple regression analysis of the association between children's internet environment, mobile phone use, developmental characteristics, and daytime exposure

	DL				UL				Wireless LAN				Digital TV				TDD			
	β	95% CI			β	95% CI			β	95% CI			β	95% CI			β	95% CI		
Internet environment																				
Number of mobile phone in the home	0.020	(-0.067	,0.108)		**0.117**	**(0.003**	**,0.230)**	*	0.077	(-0.037	,0.192)		-0.036	(-0.142	,0.070)		**0.118**	**(0.017**	**,0.218)**	*
Limitation of Internet use for children (n/y)																				
Weekday	0.025	(-0.161	,0.211)		-0.061	(-0.308	,0.186)		0.150	(-0.094	,0.393)		-0.017	(-0.242	,0.209)		-0.047	(-0.268	,0.173)	
Weekend/holidays	0.039	(-0.140	,0.219)		-0.059	(-0.297	,0.180)		0.069	(-0.167	,0.306)		-0.093	(-0.309	,0.124)		-0.097	(-0.309	,0.115)	
Type of house (Detached house or apartment complex)	**0.201**	**(0.009**	**,0.393)**	*	0.169	(-0.092	,0.431)		-0.023	(-0.285	,0.238)		0.029	(-0.211	,0.269)		**0.358**	**(0.143**	**,0.574)**	**
Area of residence (rural/urban)	**0.292**	**(0.067**	**,0.517)**	**	**0.345**	**(0.044**	**,0.647)**	*	-0.120	(-0.429	,0.189)		**0.360**	**(0.088**	**,0.631)**	*	**0.559**	**(0.312**	**,0.806)**	**
Use of cordless phone (n/y)	-0.114	(-0.345	,0.117)		-0.257	(-0.561	,0.046)	†	0.173	(-0.132	,0.477)		-0.123	(-0.403	,0.157)		**-0.299**	**(-0.566**	**-0.032)**	*
Use of wearable devices (n/y)	0.022	(-0.225	,0.269)		-0.064	(-0.392	,0.263)		0.200	(-0.123	,0.523)		0.171	(-0.125	,0.468)		0.064	(-0.228	,0.357)	
Children have their own cell phones (n/y)	0.118	(-0.067	,0.302)		0.182	(-0.062	,0.427)		0.112	(-0.134	,0.357)		0.052	(-0.174	,0.278)		**0.232**	**(0.017**	**,0.447)**	*
Mobile phone usage																				
Call using mobile phone (n/y)																				
Weekday	0.101	(-0.094	,0.296)		0.134	(-0.122	,0.390)		0.052	(-0.205	,0.309)		0.103	(-0.131	,0.337)		**0.239**	**(0.015**	**,0.463)**	*
Weekend/holidays	0.129	(-0.066	,0.324)		0.181	(-0.075	,0.437)		-0.033	(-0.292	,0.225)		0.054	(-0.182	,0.289)		**0.248**	**(0.024**	**,0.473)**	*
Call using internet protocol (n/y)																				
Weekday	0.035	(-0.167	,0.238)		-0.143	(-0.407	,0.122)		0.058	(-0.208	,0.323)		-0.012	(-0.254	,0.231)		0.148	(-0.087	,0.384)	
Weekend/holidays	0.136	(-0.076	,0.348)		-0.021	(-0.302	,0.261)		0.019	(-0.262	,0.300)		0.078	(-0.177	,0.334)		0.234	(-0.011	,0.480)	†
Video viewing using mobile phone (n/y)																				
Weekday	0.127	(-0.083	,0.338)		0.234	(-0.040	,0.508)	†	**0.279**	**(0.008**	**,0.550)**	*	0.221	(-0.028	,0.469)	†	**0.342**	**(0.105**	**,0.579)**	*
Weekend/holidays	0.035	(-0.177	,0.246)		0.237	(-0.036	,0.510)	†	0.144	(-0.131	,0.420)		**0.270**	**(0.024**	**,0.516)**	*	**0.260**	**(0.019**	**,0.501)**	*
Internet search using mobile phone (n/y)																				

Weekday	0.010	(-0.199	,0.220)		0.086	(-0.188	,0.360)		0.223	(-0.047	,0.492)		0.152	(-0.096	,0.400)		0.086	(-0.158	,0.331)	†
Weekend/holidays	0.007	(-0.197	,0.211)		0.151	(-0.114	,0.417)		0.242	(-0.019	,0.503)	†	0.065	(-0.178	,0.308)		0.134	(-0.103	,0.371)	
Text message service using mobile phone (n/y)																				
Weekday	0.226	(-0.006	,0.459)	†	-0.033	(-0.346	,0.280)		0.045	(-0.267	,0.357)		-0.016	(-0.301	,0.269)		**0.284**	**(0.012**	**,0.556)**	*
Weekend/holidays	**0.426**	**(0.148**	**,0.704)**	**	0.208	(-0.176	,0.593)		0.060	(-0.326	,0.446)		-0.013	(-0.365	,0.339)		**0.429**	**(0.097**	**,0.761)**	*
Streaming audio using mobile phone (n/y)																				
Weekday	-0.032	(-0.246	,0.181)		0.128	(-0.151	,0.407)		0.250	(-0.024	,0.524)	†	**0.279**	**(0.031**	**,0.526)**	*	0.113	(-0.136	,0.362)	
Weekend/holidays	-0.007	(-0.212	,0.198)		0.090	(-0.179	,0.358)		0.167	(-0.099	,0.433)		**0.285**	**(0.049**	**,0.521)**	*	0.107	(-0.133	,0.346)	
Online game using mobile phone (n/y)																				
Weekday	0.127	(-0.107	,0.362)		0.169	(-0.140	,0.477)		0.287	(-0.016	,0.590)	†	0.048	(-0.234	,0.331)		**0.285**	**(0.015**	**,0.554)**	*
Weekend/holidays	0.103	(-0.128	,0.333)		0.172	(-0.131	,0.474)		**0.314**	**(0.019**	**,0.610)**	*	-0.002	(-0.280	,0.275)		0.263	(-0.003	,0.528)	†
Social networking service using mobile phone (n/y)																				
Weekday	0.107	(-0.240	,0.453)		0.040	(-0.417	,0.497)		0.200	(-0.254	,0.653)		0.005	(-0.411	,0.421)		-0.172	(-0.578	,0.234)	
Weekend/holidays	0.107	(-0.240	,0.453)		0.040	(-0.417	,0.497)		0.200	(-0.254	,0.653)		0.005	(-0.411	,0.421)	†	-0.172	(-0.578	,0.234)	
Developmental characteristics																				
SDQ (normal/borderline-high)																				
TDS	-0.044	(-0.300	,0.212)		-0.054	(-0.392	,0.285)		-0.178	(-0.511	,0.155)		0.131	(-0.177	,0.440)		-0.135	(-0.438	,0.167)	
Conduct problems	-0.152	(-0.480	,0.176)		-0.368	(-0.795	,0.060)	†	-0.168	(-0.598	,0.262)		-0.093	(-0.492	,0.305)		-0.084	(-0.475	,0.307)	
Hyperactivity/Inattention	0.012	(-0.262	,0.286)		0.012	(-0.351	,0.374)		0.079	(-0.280	,0.437)		-0.138	(-0.468	,0.192)		-0.005	(-0.331	,0.320)	
Emotional Symptoms	-0.091	(-0.315	,0.134)		-0.048	(-0.345	,0.249)		0.104	(-0.189	,0.398)		-0.021	(-0.293	,0.251)		-0.215	(-0.477	,0.048)	
Peer problems	-0.076	(-0.423	,0.270)		0.128	(-0.330	,0.585)		-0.180	(-0.632	,0.273)		0.037	(-0.382	,0.457)		-0.141	(-0.551	,0.269)	
Prosocial Behavior	-0.152	(-0.369	,0.064)		0.010	(-0.280	,0.300)		-0.070	(-0.356	,0.217)		0.120	(-0.143	,0.384)		0.168	(-0.089	,0.425)	
Internet addiction tendency	-0.005	(-0.018	,0.009)		-0.001	(-0.019	,0.016)		-0.015	(-0.032	,0.003)	†	0.008	(-0.008	,0.024)		-0.003	(-0.019	,0.013)	

Adjusted regression coefficients (β) and 95% confidence intervals (CIs) for the association between questionnaire factors and $\log_{10}$-transformed RF-EMF exposure levels as determined by a linear regression model.

Each factors was introduced into the model separately and adjusted for children's sex, age, family income.
DL: Downlink, UL: Uplink, Wi-Fi: Wireless Fidelity, TDD: Time Division Duplex. TDS: Total Difficulty Score ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$

Table 6. Results of multiple regression analysis of the associations between children's internet environment, mobile phone use, developmental characteristics, and nighttime exposure

	DL			UL			Wireless LAN			Digital TV			TDD		
	β	95% CI		β	95% CI		β	95% CI		β	95% CI		β	95% CI	
Internet environment															
Number of mobile phones in the home	0.034	(-0.125 ,0.194)		0.075	(-0.092 ,0.242)		0.106	(-0.075 ,0.287)		-0.047	(-0.179 ,0.085)		0.114	(-0.125 ,0.353)	
Limitation of Internet use for children (n/y)															
Weekday	0.047	(-0.292 ,0.386)		-0.127	(-0.482 ,0.228)		0.220	(-0.165 ,0.605)		-0.011	(-0.292 ,0.270)		0.141	(-0.360 ,0.642)	
Weekend/holidays	0.025	(-0.303 ,0.352)		-0.173	(-0.515 ,0.168)		0.092	(-0.282 ,0.465)		-0.078	(-0.348 ,0.193)		0.006	(-0.480 ,0.492)	
Type of house (Detached house or apartment complex)	-0.039	(-0.400 ,0.323)		0.102	(-0.277 ,0.482)		0.076	(-0.339 ,0.490)		-0.067	(-0.367 ,0.233)		0.495	(-0.029 ,1.019)	†
Area of residence (rural/urban)	**0.504**	**(0.092 ,0.915)**	*	0.269	(-0.175 ,0.713)		-0.319	(-0.802 ,0.164)		0.121	(-0.231 ,0.474)		0.612	(-0.020 ,1.245)	†
Use of cordless phone (n/y)	0.101	(-0.322 ,0.524)		-0.274	(-0.715 ,0.166)		-0.085	(-0.569 ,0.399)		-0.081	(-0.432 ,0.269)		-0.328	(-0.964 ,0.309)	
Use of wearable devices (n/y)	-0.011	(-0.461 ,0.439)		0.020	(-0.452 ,0.492)		0.235	(-0.276 ,0.746)		0.277	(-0.090 ,0.644)		0.302	(-0.378 ,0.983)	
Children have their own cell phones (n/y)	0.027	(-0.313 ,0.367)		0.134	(-0.221 ,0.490)		0.170	(-0.217 ,0.557)		-0.086	(-0.367 ,0.195)		0.333	(-0.172 ,0.839)	
Mobile phone usage															
Call using mobile phone (n/y)															
Weekday	-0.005	(-0.358 ,0.347)		0.078	(-0.293 ,0.450)		-0.069	(-0.473 ,0.336)		0.008	(-0.284 ,0.300)		0.317	(-0.206 ,0.841)	
Weekend/holidays	0.012	(-0.342 ,0.366)		0.135	(-0.237 ,0.506)		-0.079	(-0.485 ,0.327)		-0.036	(-0.329 ,0.257)		0.150	(-0.380 ,0.679)	
Call using internet protocol (n/y)															
Weekday	0.080	(-0.283 ,0.444)		-0.188	(-0.569 ,0.193)		0.100	(-0.316 ,0.517)		0.157	(-0.142 ,0.456)		0.202	(-0.337 ,0.740)	
Weekend/holidays	0.040	(-0.344 ,0.425)		-0.187	(-0.590 ,0.217)		-0.076	(-0.517 ,0.365)		0.075	(-0.243 ,0.393)		0.231	(-0.347 ,0.808)	
Video viewing using mobile phone (n/y)															
Weekday	0.190	(-0.188 ,0.569)		0.266	(-0.131 ,0.663)		0.293	(-0.139 ,0.725)		0.152	(-0.161 ,0.466)		**0.617**	**(0.072 ,1.163)**	*
Weekend/holidays	0.157	(-0.221 ,0.535)		0.381	(-0.010 ,0.772)	†	0.140	(-0.295 ,0.575)		0.143	(-0.170 ,0.456)		0.544	(-0.005 ,1.092)	†
Internet search using mobile phone (n/y)															
Weekday	-0.194	(-0.566 ,0.179)		-0.077	(-0.473 ,0.318)		0.364	(-0.059 ,0.787)	†	0.092	(-0.218 ,0.402)		0.306	(-0.254 ,0.866)	
Weekend/holidays	-0.117	(-0.482 ,0.248)		-0.105	(-0.489 ,0.280)		0.299	(-0.115 ,0.713)		-0.067	(-0.369 ,0.235)		0.293	(-0.252 ,0.838)	

Text message service using mobile phone (n/y)																				
Weekday	0.245	(-0.179	,0.669)		-0.105	(-0.555	,0.346)		-0.067	(-0.557	,0.424)		-0.032	(-0.386	,0.323)		0.106	(-0.528	,0.739)	
Weekend/holidays	**0.617**	**(0.107**	**,1.127)**	*	0.028	(-0.529	,0.586)		0.197	(-0.408	,0.803)		0.139	(-0.298	,0.576)		0.724	(-0.042	,1.490)	†
Streaming audio using mobile phone (n/y)																				
Weekday	-0.063	(-0.446	,0.319)		0.158	(-0.245	,0.560)		0.221	(-0.216	,0.658)		0.145	(-0.170	,0.461)		0.420	(-0.152	,0.991)	
Weekend/holidays	0.185	(-0.180	,0.551)		0.261	(-0.122	,0.645)		0.263	(-0.155	,0.681)		0.199	(-0.102	,0.500)		**0.549**	**(0.010**	**,1.089)**	*
Online game using mobile phone (n/y)																				
Weekday	0.110	(-0.313	,0.534)		0.394	(-0.045	,0.832)	†	0.461	(-0.015	,0.937)	†	-0.061	(-0.412	,0.290)		0.395	(-0.227	,1.016)	
Weekend/holidays	-0.047	(-0.463	,0.369)		0.382	(-0.048	,0.812)	†	**0.495**	**(0.031**	**,0.960)**	*	-0.100	(-0.444	,0.244)		0.324	(-0.288	,0.935)	
Social networking service using mobile phone (n/y)																				
Weekday	-0.133	(-0.756	,0.491)		0.069	(-0.588	,0.727)		0.209	(-0.506	,0.924)		-0.165	(-0.681	,0.350)		0.176	(-0.744	,1.096)	
Weekend/holidays	-0.133	(-0.756	,0.491)		0.069	(-0.588	,0.727)		0.209	(-0.506	,0.924)		-0.165	(-0.681	,0.350)		0.176	(-0.744	,1.096)	
Developmental characteristics																				
SDQ (normal/ borderline-high)																				
TDS	0.377	(-0.083	,0.836)		0.382	(-0.100	,0.865)		0.019	(-0.516	,0.553)		0.313	(-0.067	,0.692)		0.091	(-0.602	,0.784)	
Conduct problems	0.062	(-0.539	,0.664)		-0.190	(-0.820	,0.440)		0.060	(-0.628	,0.748)		-0.094	(-0.590	,0.403)		0.427	(-0.455	,1.309)	
Hyperactivity/Inattention	0.225	(-0.272	,0.723)		0.315	(-0.205	,0.834)		**0.737**	**(0.191**	**,1.283)**	**	0.058	(-0.355	,0.471)		0.214	(-0.524	,0.952)	
Emotional Symptoms	0.106	(-0.304	,0.516)		0.107	(-0.323	,0.537)		-0.127	(-0.595	,0.342)		0.169	(-0.168	,0.505)		-0.349	(-0.962	,0.265)	
Peer problems	0.065	(-0.568	,0.698)		0.358	(-0.301	,1.017)		-0.147	(-0.869	,0.576)		0.269	(-0.250	,0.788)		-0.646	(-1.566	,0.274)	
Prosocial Behavior	-0.042	(-0.442	,0.358)		0.057	(-0.363	,0.476)		-0.130	(-0.587	,0.326)		0.039	(-0.291	,0.369)		0.381	(-0.221	,0.983)	
Internet addiction tendency	0.012	(-0.012	,0.036)		0.015	(-0.011	,0.040)		-0.014	(-0.042	,0.014)		0.008	(-0.012	,0.029)		-0.020	(-0.056	,0.016)	

Adjusted regression coefficients (β) and 95% confidence intervals (CIs) for the association between questionnaire factors and $\log_{10}$-transformed RF-EMF exposure levels as determined by a linear regression model.

Each factor was introduced into the model separately and adjusted for children's sex, age, family income.

DL: Downlink, UL: Uplink, Wireless LAN: Wireless Fidelity, TDD: Time Division Duplex (See also Table 1), TDS: Total Difficulty Score ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$

Table 7. Recent studies on personal exposure levels recorded by ExpoM-RF

Author	Published	Recording	Place	Number of	Age	Exposure		$\mu W/m^2$	mV/m
Present study	-	Mar. 2020.3- Apr. 2021	Hokkaido, Japan	101	10-16 y	ExpoM-RF JP	Total	43.3	127.8
							Daytime	55.3	144.4
							Nighttime	20.2	87.3
Zeleke et al.	2018	June-Nov. 2017	Melbourne,	63	mean	ExpoM-RF	Total	114.8	208
Gallastegi et	2018	2014-2016	Basque Country,	50	8 y	ExpoM-RF3	Total	52.13	140.2
Birks et al.	2018	Sep. 2014-Feb. 2016 (reported in Eeftens et al.,	Denmark, the Netherlands, Slovenia,	529	8-18 y	ExpoM-RF	Total	75.5	168.7
							Daytime	94.2	188.4
							Nighttime	23	93.1
Choi et al.	2018	Sep.-Dec. 2016	Seoul, Cheonan, and Ulsan, South Korea	50	Child (6-9 y)-adult	ExpoM-RF	Children	26.17	99.3
							Father	32.44	110.6
							Mother	31.28	108.6

Supplementary material

Table S1 Prevalence of the timepoint when the measured value was below two times of noise level for all participants (%).

	Mean	±SD	Min	Median	Max
Digital TV	27.3	±23.8	0.0	22.2	98.0
700 MHz UL	98.5	±3.5	72.0	99.5	100.0
700 MHz DL	59.4	±32.2	1.2	63.8	99.8
800 MHz UL	88.6	±18.2	12.0	97.9	100.0
800 MHz DL	9.1	±18.0	0.0	2.0	89.9
900 MHz UL	4.3	±10.2	0.0	0.3	56.2
900 MHz DL	29.3	±27.7	0.0	21.6	90.0
1.5 GHz DL	13.8	±21.9	0.0	3.6	92.4
1.7 GHz UL	98.9	±3.0	79.9	99.8	100.0
1.9 GHz	90.9	±15.0	8.3	97.3	100.0
2.1 GHz UL	95.4	±7.1	47.2	97.4	99.8
2.1 GHz DL	1.6	±5.4	0.0	0.0	37.9
ISM 2.4 GHz	25.0	±17.3	0.1	23.0	85.8
2.5 GHz TDD	19.4	±25.7	0.0	7.1	94.0
3.5 GHz TDD	29.6	±30.0	0.0	16.5	99.1
ISM 5.8 GHz	19.3	±16.5	0.1	14.9	68.8

DL: Downlink, UL: Uplink, WiFi: Wireless Fidelity , TDD: Time Division Duplex , ISM: Industrial Scientific and Medical