Patterns of cellular phone use among young people in 12 countries: Implications for RF exposure

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Abstract

Characterizing exposure to radiofrequency (RF) fields from wireless telecommunications technologies during childhood and adolescence is a research priority in investigating the health effects of RF. The Mobi-Expo study aimed to describe characteristics and determinants of cellular phone use in 534 young people (10–24 years) in 12 countries. The study used a specifically designed software application installed on smartphones to collect data on the use of wireless telecommunications devices within this age group. The role of gender, age, maternal education, calendar period, and country was evaluated through multivariate models mutually adjusting for all variables. Call number and duration were higher among females compared to males (geometric mean (GM) ratio 1.17 and 1.42, respectively), among 20–24 year olds compared to 10–14 year olds (GM ratio 2.09 and 4.40, respectively), and among lowest compared to highest social classes (GM ratio 1.52 and 1.58, respectively). The number of SMS was higher in females (GM ratio 1.46) and the middle age group (15–19 year olds: GM ratio 2.21 compared to 10–14 year olds) and decreased over time. Data use was highest in the oldest age group, whereas Wi-Fi use was highest in the middle age group. Both data and Wi-Fi use increased over time. Large differences in the number and duration of calls, SMS, and data/Wi-Fi use were seen by country, with country and age accounting for up to 50% of the variance. Hands-free and laterality of use did not show significant differences by sex, age, education, study period, or country. Although limited by a convenience sample, these results provide valuable insights to the design, analysis, and interpretation of future epidemiological studies concerning the health effects of exposure resulting from cellular phone use in young people. In addition, the information provided by this research may be used to design strategies to minimize RF exposure.

1. Introduction

Concern about the potential health effects of exposure to radiofrequency (RF) fields has increased over the last decades, particularly in light of the rapid increase in cellular phone use worldwide. In recent years, the way in which cellular phones are used has also changed dramatically with the arrival of third generation (3G) and fourth generation long-term evolution (4G-LTE) telecommunication standards, as well as smartphones and software applications. If there is a health risk related to RF from cellular phones, it would likely be greater among young people because: the developing neurological system may be more sensitive to RF; the spatial distribution of RF absorption in the brain of young people may be different than in adults; and the specific absorption rate (SAR) is higher in children than adults (Wiart et al., 2008, Wiart et al., 2011). Because of these concerns, a number of national and international bodies have recommended studies of exposure in childhood and adolescence as high priority areas for RF research (WHO, 2010, NRC, 2008).

Epidemiological studies of the potential health risks associated with cellular phone use generally rely on self-reported number and duration of calls to characterize RF exposure (Vrijheid et al., 2006, Vrijheid et al., 2009a, INTERPHONE Study Group, 2010, Frei et al., 2011, Aydin et al., 2011, Divan et al., 2012, Hardell et al., 2013, Carlberg and Hardell, 2015, Hardell and Carlberg, 2015, Sadetzki et al., 2014). In addition to the number and duration of calls, many other factors can affect the actual RF exposure, including positions of use (laterality, hands-free kits), the time spent using the phone for non-voice call purposes, and type of cellular network (e.g., 2G and 3G) (Vrijheid et al., 2009b, Cardis et al., 2011a, Cardis et al., 2011b). As the absorption of RF emitted by cellular phones is very localized, the position in which the phone is held (close to the head or farther away) and the laterality (right or left side of the head) are important determinants of exposure (Cardis et al., 2011a). Further, phones operating under different cellular networks can have appreciably different output power due to more efficient power control and handover management in the newer networks (Vrijheid et al., 2009b). This can have a large influence on the total output power of the cellular phone and thus on the energy potentially absorbed by the user. Newer uses of phones (Internet, games, music, etc.) have led to marked changes in the proportion of phone use time dedicated to voice calls, particularly among young people. This has important implications for exposure assessment as only voice calls made with the phone near the head (without hands-free kit or speaker) result in any substantial absorption of RF energy inside the head.

To improve exposure indices in epidemiological studies of RF risks in young people, it is important to account for phone use characteristics that are unique to young people and to modern cellular phone networks. However, such phone use characteristics and their determinants are not well described. Descriptions are largely limited to the percentage of children or young people using cell phones (Schüz, 2005), or average numbers of calls, text messages and other phone uses without evaluating the determinants of use characteristics (Aydin et al., 2011, Divan et al., 2012, Roser et al., 2016). A recent study in Denmark found that low socioeconomic status was associated with making more voice calls at age 7 but not at age 11, and that boys use phones for talking and texting less than girls (Sudan et al., 2016). In the Netherlands, children aged 5–6 years who made more calls per week had mothers from lower social classes (Guxens et al., 2016). Given our limited understanding of what determines phone use in children and young people, there is a need for large international studies examining patterns of use and how determinants such as age, sex, country and socio-economic status affect cell phone use characteristics that in turn influence RF exposure.

The Mobi-Expo study therefore aims to describe cellular phone use characteristics and determinants in children, adolescents, and young adults between the ages of 10 and 24 years in 12 countries worldwide. The study used a specifically designed software application installed on smartphones to collect data from volunteers on the number and duration of voice calls, data and Wi-Fi use, hands-free devices, laterality, and network type.

2. Methods

The Mobi-Expo study was conducted within the framework of MOBI-Kids (Sadetzki et al., 2014), an epidemiologic study of the potential association of cellular phone use and the risk of brain tumors in young people. Mobi-Expo collected data from volunteers in the countries and age groups participating in MOBI-Kids. Within MOBI-Kids, the proposed age range (10 to 24 years) was determined to be the most cost efficient approach to account for latency of brain cancer risk from exposure in childhood/adolescence. Study materials, including the protocol and questionnaires, were finalized after a pilot study in three countries, previously described by Goedhart et al. (2015).

2.1. Characteristics of the smartphone application

Whist Lab (Paris, France) developed a smartphone software application in Java that can be installed on any regular smartphone working under the Android OS. This app, called “XMobiSense,” internally records data on phone use. The Android OS allows access to information provided by the phone's proximity detector, global positioning system (GPS), accelerometer, and magneto sensors. XMobiSense records the following information: date and time of voice calls; duration of voice calls; laterality (right, left, hands-free kit, speaker) based on angles and proximity detector data obtained from sensors on the cellular phone; number of SMS sent and received; quantity of transmitted and received data via both cellular data and Wi-Fi connection; and network type and communication protocol during voice calls: GPRS (General Packet Radio Service – a 2G transitional protocol), EDGE (Enhanced Data rates for Global Evolution – 2G transitional), UMTS (Universal Mobile Telephone System - 3G IMT-2000 protocol), HSDPA (High-Speed Down-Link Packet Access – a 3G transitional protocol), and other.

No identifying information is recorded by XMobiSense. Piloting of the app (Goedhart et al., 2015) revealed some errors in certain phone models in recording laterality and hands-free use. As such, analyses concerning laterality and hands-free usage were restricted to the following phone models for which errors did not occur: Samsung Galaxy Ace, S, S (Plus), S2, S3, S3 (mini), S4, and S4 (mini). Data from the app were either downloaded or transferred automatically via secure file transfer protocol (FTP) and processed with specially developed software to obtain summary information on use characteristics.

2.2. Participant recruitment

Volunteers were recruited in 12 of the 14 countries participating in MOBI-Kids (Australia, Canada, France, Germany, Greece, Israel, Italy, Japan, Korea, New Zealand, Spain, and The Netherlands). Volunteers without an Android phone ("study-phone users") borrowed an Android phone to use during the study period. Participants with an Android phone ("own-phone users") installed XMobiSense on their own phone. All countries followed the core Mobi-Expo protocol.

Volunteers had to be between the ages of 10 and 24 years old during the month they used the phone. In addition, volunteers had to currently use a cellular phone on average at least once a week to be eligible. Subjects were excluded if they could not speak the MOBI-Kids coordinating center's main language(s) or if they did not live in the study area defined in MOBI-Kids. An effort was made to recruit volunteers of both sexes from a range of socioeconomic statuses and geographical areas.

Centers primarily recruited volunteers through their networks of family members, friends, and colleagues. Although most centers restricted Mobi-Expo to the metropolitan area where the MOBI-Kids coordinating center is located, France expanded the area to the regions included in MOBI-Kids (except Hérault); Israel, New Zealand, and The Netherlands (own-phone users only) recruited volunteers nation-wide (Table 1). Greece, Japan, Korea, and New Zealand only recruited volunteers using their own phones; the rest of the centers recruited both study-phone and own-phone users (Table 1).

Table 1. Mobi-Expo countries, participating regions, recruitment strategies, recruitment periods, and numbers of volunteers.

Country	**Region**	**Recruitment strategies**	**Recruitment period**	**Volunteers recruited (n)**			**Included in analysis (n)**
				Own phone	**Study phone**	**Total**	**Total**
Australia	Suburban areas of Melbourne, Victoria	Advertised on the Monash University website and in athletic clubs across Melbourne	October 2012–February 2013	3	35	38	34
Canada	Ottawa, Ontario	Sent hospital-wide emails to employees of pediatric and adult hospitals participating in MOBI-Kids and advertised on university research participation program website	January 2014–April 2014	24	22	46	38
France	Urban and rural areas in Lorraine, Ile-de-France, Rhône-Isère, Hérault, Bouches-du-Rhône, Alsace, Gironde	Contacted family and friends of MOBI-Kids interviewers in each region and advertised amongst faculty, in schools/associations/halls where young people congregate, and on social media (e.g., facebook)	April 2013–September 2013	16	33	49	45
Germany	Munich and rural parts of Bavaria	Advertised in the coordinating center hospital's intranet and sent email to colleagues, family and friends	February 2013–July 2014	25	12	37	34
Greece	Athens and suburban areas	Received list of eligible young people from collaborating pediatricians in public and private practices, contacted schools to recruit younger volunteers, and advertised in Medical School of Athens	March 2014–July 2014	54		54	44
Israel	Nationwide	Posted signs in the Sheba Medical Center, recruited participants among	August 2013–July 2014	26	25	51	42

Country	Region	Recruitment strategies	Recruitment period	Volunteers recruited (n)			Included in analysis (n)
				Own phone	Study phone	Total	Total
		family members, friends, neighbors, and acquaintances, and approached potential volunteers during after school activities.					
Italy	Piedmont	Sent email to all staff at research institute and presented study to select classes at the university: medical students, nurses, midwives, etc.	October 2013–July 2014	23	42	65	61
Japan	Tokyo metropolitan area	Recruited volunteers through a research company managing a large-scale Internet research panel	December 2013–March 2014	28		28	23
Korea	Seoul and Gyeonggi province	Recruited volunteers among family, friends, and acquaintances, and presented study to school teachers and students at Dankook University	October 2013–December 2013	53		53	51
New Zealand	Wellington, Palmerston North and Auckland metropolitan areas	Contacted Massey University staff across the three campuses	May 2014–July 2014	23		23	22
Spain	Barcelona and rural parts of Catalonia	Advertised study to scouts organizations, approached potential volunteers from a list of young people interested in participating in scientific studies, contacted schools, and sent email to friends and relatives	October 2012–March 2014	24	34	58	58
The Netherlands	Own phone: Nationwide Study phone: Utrecht and surrounding villages	Advertised on website designed to recruit study volunteers, posted flyers at Utrecht University, contacted a secondary school, and approached colleagues' family and friends	October 2012–January 2014	57	28	85	82
Total				356	231	587	534

Ethics approvals for conducting this study were obtained in each country in accordance with the requirements of local ethics committees. As the study involved adults and children, consent requirements varied between ages and centers. All participants provided informed consent, either alone or with a parent/guardian, before participating in the study.

2.3. Study participation

Participants were recruited between October 2012 and July 2014. Volunteers were instructed to use a phone with XMobiSense installed for a period of four weeks. For study-phone users, volunteers between 10 and 14 years old were provided with a Samsung Galaxy Mini GT-S5570, while volunteers 15 years and older used a Samsung Galaxy SII I9100. The phone models were chosen based on a finding from the pilot study that parents were generally uncomfortable with their young children using a top-of-the-line smartphone. XMobiSense was installed prior to phone distribution. Study-phone users placed their SIM card into the smartphone and were instructed to use it as if it were their own phone. Own-phone users simply installed XMobiSense and continued using their phone as normal. Short screening questionnaires covering basic demographic information (including age and parental education) as well as baseline cellular phone use (number and duration of calls, data use, etc.) were administered to participants at the beginning of their participation. After four weeks, the volunteers returned the phones or un-installed XMobiSense (after sending the logfile). The study-phone users were asked to complete a questionnaire detailing any changes in their cellular phone use during the study period.

A total of 587 volunteers were recruited in the 12 countries (Table 1); for these participants both questionnaires and at least 8 days of XMobiSense data were collected. Final analyses included 534 participants (321 own-phone and 213 study-phone users) and excluded 53 participants for whom errors were found in a substantial proportion of the call registers (e.g., more than 5% of total calls were registered with 0 duration or with a duration of over 4 h).

2.4. Statistical analyses

Questionnaire information on maternal education level was country-specific and collapsed to a tri-categorical variable (low/medium/high). “Low” education indicates completion of secondary school or less; “medium” education includes attendance or completion of medium-level technical or professional school; and “high” education indicates a university degree or higher. Age was analyzed in three categories: 10–14 years, 15–19 years, 20–24 years. A “study period” variable was defined based on four to six month intervals, each covering data collection periods in at least 3 countries (October 2012–March 2013, April 2013–September 2013, October 2013–March 2014, and April 2014–July 2014). Phone use characteristics analyzed were: number of calls (per week), duration of calls (minutes per week), number of SMS sent and received (per week), cellular data and Wi-Fi used (Mb per week), percent hands-free use (percent of total talk time spent with phone away from the head, including speaker phone and hands-free kit), percent right-hand laterality (percent of time with phone on right side of head out of the total call time near the head) and voice call time in each of 5 network communications protocols (GPRS, EDGE, UMTS, HSDPA, and other).

Simple univariate and bivariate analyses were performed to describe characteristics of cellular phone use by the explanatory variables: gender, age, maternal education level, study period, and country. The percentage of voice call time in each of the five different network communication protocols (see above) was shown descriptively by country.

In multivariate models, all explanatory variables were entered in one model for mutual adjustment. We calculated the adjusted geometric mean (GM) and geometric mean ratio (GM ratio) and 95% confidence intervals (95% CI) for number and duration of calls, number of SMS sent and received, and cellular data and Wi-Fi used. Percent hands-free use and percent right-handed laterality were analyzed through calculations of the adjusted mean percentage use and the odds ratio based on generalized linear logistic regression models. It should be noted that hands-free time includes use of hands-free kits, speaker phone, and miscellaneous time spent with the phone away from the head, e.g. when answering or ending phone calls. Analyses on laterality and hands-free usage were restricted to users of the Samsung Galaxy Ace, S, S (Plus), S2, S3, S3 (mini), S4, and S4 (mini), as detailed above (N = 248).

Finally, analysis-of-variance (ANOVA) models were applied to calculate the proportion of the total variability in phone use characteristics explained by the explanatory variables identified above. We applied an ANOVA type-I sum of squares, or sequential, model, including explanatory variables in order of descending percentage of variability explained for each variable in univariate ANOVA models. All analyses were done in Stata (StataCorp, Release 13, 2013).

3. Results

3.1. Study participants

Of the 534 participants included in the analyses, 63% were female. Most subjects were in the older age groups (23% 10–14 year olds; 34% 15–19 year olds; and 43% 20–24 year olds). Almost half of the participants' mothers had attained the highest level of education (university degree or higher).

3.2. Voice calls

Participants made on average 30.6 calls per week (median 20.9) and spent 60.8 min per week making or receiving calls (median 34.3; Table 2). Given the large variation, and skewed distributions, the geometric mean is used for analyses. Compared to males, females made or received 17% more calls (adj GM ratio 1.17; 95% CI: 1.00, 1.38) and spent 42% more time on voice calls (adj GM ratio 1.42; 95% CI: 1.16, 1.75), after adjustment for the other explanatory variables: age, maternal education, time period and country (Table 3). Older age (20–24 years) was associated with both a higher number of calls and a longer total duration of voice calls. For example, compared to the youngest age group (10–14 year olds), the oldest age group (20–24 year olds) made over twice as many phone calls (adj GM ratio 2.09; 95% CI: 1.70, 2.58) and spent almost four and a half times as long on the phone (adj GM ratio 4.40; 95% CI: 3.37, 5.73). Number and duration of calls were higher at lower levels of maternal education: the lowest education group made approximately 50% more calls and spent about 60% more time on voice calls compared to the highest maternal education level (adj GM ratios 1.52; 95% CI: 1.26, 1.83 and 1.58; 95% CI: 1.25, 1.99 for number and duration of calls, respectively). A lower number and duration of calls were observed in the later study periods compared to the earlier (adj GM ratios April–July 2014 compared to October 2012–March 2013, respectively: 0.52; 95% CI 0.26, 1.02 and 0.59; 95% CI 0.30, 1.19). The largest differences in voice calls were by country. Volunteers in Greece had the highest number and longest duration, with GMs of 56.7 calls per week and 86.6 min per week. Volunteers in Israel, Italy, and Korea also had higher number and longer duration spent on voice calls compared to the other countries. In contrast, volunteers in Japan had the fewest calls and the shortest duration, with GM 4.4 calls per week and 5.1 min per week (Table 3).

Table 2. Distribution of phone use variables

	N	Mean (SD)	Median (IQR)	Min–max
Number of calls per week	534	30.6 (32.0)	20.9 (29.0)	0.2–225.4
Total duration in minutes per week	534	60.8 (80.1)	34.3 (65.3)	0.1–923.0
Number of SMS sent and received per week	534	106.3 (251.7)	26.6 (80.5)	0–2398.2
Data use per week (Mb)	534	121.4 (246.8)	36.1 (116.4)	0–2579.5
Wi-Fi use per week (Mb)	534	768.1 (1352.4)	249.2 (733.5)	0–11428.7
% hands-free of total call time	248	18.8 (20.3)	10.6 (18.1)	0.6–98.0
% right-handed laterality of call time near head	248	63.8 (25.3)	70.8 (37.2)	0–99.9

SD: standard deviation; IQR: interquartile range.

Table 3. Adjusted[a] geometric mean and geometric mean ratio of number and total duration of calls per week by explanatory variables.

	N	Number of calls per week		Total duration in minutes per week	
		GM	GM ratio (95% CI)	GM	GM ratio (95% CI)
Overall	534	18.8		29.4	

	N	Number of calls per week		Total duration in minutes per week	
		GM	GM ratio (95% CI)	GM	GM ratio (95% CI)
Gender					
Male	200	17.0	1	23.6	1
Female	334	19.9	1.17 (1.00; 1.38)	33.6	1.42 (1.16; 1.75)□
Age group					
10–14 years	123	12.0	1	12.0	1
15–19 years	184	17.6	1.45 (1.17; 1.80)□	25.8	2.15 (1.62; 2.85)□
20–24 years	227	25.2	2.09 (1.70; 2.58)□	52.9	4.40 (3.37; 5.73)□
Maternal education					
High	250	15.6	1	24.2	1
Medium	122	19.3	1.23 (1.01; 1.51)□	30.5	1.26 (0.98; 1.62)
Low	117	23.7	1.52 (1.26; 1.83)□	38.2	1.58 (1.25; 1.99)□
Unknown	45	25.7	1.64 (1.21; 2.23)□	39.6	1.64 (1.09; 2.46)□
Period					
Oct 2012–March 2013	121	21.7	1	30.1	1
April 2013–Sept 2013	125	23.6	1.09 (0.80; 1.47)	35.4	1.18 (0.79; 1.75)
Oct 2013–March 2014	224	17.6	0.81 (0.56; 1.17)	30.1	1.00 (0.65; 1.55)
April 2014–July 2014	64	11.3	0.52 (0.26; 1.02)	17.9	0.59 (0.30; 1.19)
Country					
Australia	34	14.4	1	24.8	1
Canada	38	17.3	1.20 (0.67; 2.15)	29.1	1.17 (0.56; 2.45)
France	45	21.7	1.51 (0.93; 2.45)	41.6	1.68 (0.89; 3.16)
Germany	34	9.9	0.69 (0.41; 1.16)	22.7	0.92 (0.46; 1.81)
Greece	44	56.7	3.95 (1.97; 7.93)□	86.6	3.50 (1.59; 7.67)□
Israel	42	46.7	3.25 (2.02; 5.25)□	66.0	2.67 (1.44; 4.94)□
Italy	61	29.9	2.08 (1.24; 3.50)□	48.9	1.97 (1.03; 3.78)□
Japan	23	4.4	0.31 (0.15; 0.61)□	5.1	0.20 (0.08; 0.53)□
Korea	51	34.2	2.38 (1.42; 3.99)□	42.9	1.73 (0.88; 3.40)
New Zealand	22	11.2	0.78 (0.33; 1.83)	16.2	0.65 (0.24; 1.75)
Spain	58	14.5	1.01 (0.70; 1.47)	19.2	0.77 (0.46; 1.30)
The Netherlands	82	9.1	0.63 (0.43; 0.94)□	15.2	0.61 (0.36; 1.05)

A Adjusted by gender, age group, mother educational level, period and country.
□ $p < 0.05$.

3.3. SMS, cellular data, and Wi-Fi use

The average number of SMS sent and received was 106.3 messages per week, with a median of 26.6 (Table 2). In terms of data transfer, participants transferred 121.4 megabytes (Mb) per week on average over cellular data (median 36.1 Mb), and 768.1 Mb per week over Wi-Fi (median 249.2) (Table 2). Females sent and received 46% more SMS than males and used 67% more cellular data, but approximately 58% less Wi-Fi compared to males (Table 4). With respect to age, the middle age group (15–19 years) sent and received the most SMS and used the most Wi-Fi. The oldest age group (20–24 years) used the most cellular data. With respect to maternal education level, the number of SMS messages did not clearly differ between educational groups, but the lowest education group tended to use more cellular data and Wi-Fi. SMS use decreased 70% from the beginning to the end of the study period, whereas use of cellular data and Wi-Fi increased between 3 and 5.5-fold over the same period. The largest differences were again by country: messages sent and received per week varied from an adjusted GM of 1.7 in Japan to 213.3 in France. Cellular data use ranged from a GM of 5.1 to 170.4 Mb transferred per week in Germany and Israel, respectively.

Geometric mean Wi-Fi use ranged from 27.6 to 1210.7 Mb transferred per week in Japan and Korea, respectively.

Table 4. Adjusted[a] geometric mean and geometric mean ratio of SMS, data use, and Wi-Fi use, by explanatory variables.

	N	Number of SMS sent and received per week		Data use per week (Mb)		Wi-Fi use per week (Mb)	
		GM	**GM ratio (95% CI)**	**GM**	**GM ratio (95% CI)**	**GM**	**GM ratio (95% CI)**
Overall	534	27.5		21.4		138.3	
Gender							
Male	200	21.7	1	15.6	1	239.7	1
Female	334	31.7	1.46 (1.18; 1.82)□	25.9	1.67 (0.92; 3.00)	99.5	0.42 (0.26; 0.66)□
Age group							
10–14 years	123	16.8	1	6.6	1	77.9	1
15–19 years	184	37.2	2.21 (1.65; 2.98)□	23.2	3.54 (1.70; 7.38)□	251.6	3.23 (1.70; 6.12)□
20–24 years	227	28.1	1.67 (1.26; 2.23)□	38.1	5.82 (2.73; 12.41)□	116.1	1.49 (0.77; 2.87)
Maternal education							
High	250	26.1	1	16.0	1	121.6	1
Medium	122	31.0	1.19 (0.91; 1.55)	25.9	1.62 (0.74; 3.54)	132.5	1.09 (0.60; 1.96)
Low	117	23.7	0.91 (0.70; 1.17)	32.5	2.03 (1.16; 3.56)□	189.4	1.56 (0.90; 2.70)
Unknown	45	39.2	1.50 (1.01; 2.23)□	21.4	1.34 (0.50; 3.56)	140.1	1.15 (0.42; 3.13)
Period							
Oct 2012–March 2013	121	44.2	1	10.2	1	95.0	1
April–Sept 2013	125	34.5	0.78 (0.54; 1.12)	11.4	1.11 (0.30; 4.07)	147.3	1.55 (0.64; 3.74)
Oct 2013–March 2014	224	23.2	0.52 (0.34; 0.82)□	34.4	3.36 (1.03; 10.92)□	130.9	1.38 (0.42; 4.48)
April–July 2014	64	13.1	0.30 (0.13; 0.67)□	56.1	5.47 (1.04; 28.73)□	300.4	3.16 (0.73; 13.72)
Country							
Australia	34	35.8	1	17.1	1	29.6	1
Canada	38	202.1	5.64 (2.61; 12.19)□	10.0	0.59 (0.07; 4.73)	458.0	15.49 (3.40; 70.56)□
France	45	213.3	5.95 (2.93; 12.09)□	12.5	0.73 (0.10; 5.23)	36.2	1.22 (0.25; 5.93)
Germany	34	11.9	0.33 (0.16; 0.69)□	5.1	0.30 (0.04; 2.08)	56.3	1.91 (0.43; 8.52)
Greece	44	35.3	0.99 (0.38; 2.58)	15.1	0.88 (0.14; 5.57)	87.3	2.95 (0.51; 17.18)
Israel	42	14.5	0.41 (0.20; 0.81)□	170.4	9.97 (2.05; 48.40)□	118.5	4.01 (0.94; 17.03)
Italy	61	68.5	1.91 (0.89; 4.09)	14.3	0.84 (0.14; 4.97)	131.9	4.46 (0.90; 22.03)
Japan	23	1.7	0.05 (0.02; 0.14)□	67.5	3.95 (0.56; 28.04)	27.6	0.93 (0.12; 7.18)
Korea	51	54.8	1.53 (0.75; 3.10)	123.4	7.22 (1.47; 35.51)□	1210.7	40.95 (8.86; 189.33)□
New Zealand	22	209.1	5.84 (2.10; 16.26)□	10.3	0.60 (0.07; 5.30)	178.5	6.04 (0.87; 41.79)
Spain	58	3.8	0.11 (0.06; 0.18)□	20.1	1.17 (0.25; 5.47)	102.9	3.48 (1.16; 10.42)□
The Netherlands	82	9.3	0.26 (0.14; 0.47)□	14.2	0.83 (0.21; 3.32)	307.0	10.38 (3.37; 32.00)□

A Adjusted by gender, age group, mother educational level, period and country.
□ $p < 0.05$.

3.4. Hands-free use and laterality

A total of 248 (46.4%) subjects had usable data for laterality. For these participants, 18.8% of total call time was "hands-free" on average (median 10.6%), i.e. using the speaker phone, a hands-free kit, or holding the phone away from the head (Table 2). Out of the total call time near the head (not "hands-free"), participants used the phone on the right side of the head in 63.8% of the time on average (median 70.8% - Table 2). With respect to gender, there was no statistically significant difference between males and females for hands-free usage, although females tended to speak somewhat less on their right-hand side (68% in males versus 61% in females, adj OR 0.75; 95% CI 0.54, 1.03). There were no notable differences by age group, maternal education level or study period for either hands-free use or right-handed laterality (Table 5). There were few differences in hands-free use or laterality between countries; volunteers in Japan, Korea and New Zealand used hands-free most. Right-sided laterality ranged from 52% in Korea to 85% in New Zealand (Table 5).

Table 5. Adjusted[a] mean percentage and odds ratio of hands-free use and right-handed laterality.

	N	% hands free		% right-handed laterality	
		Mean	**OR**	**Mean**	**OR**
Overall	248	18.1		63.8	
Gender					
Male	93	17.2	1	67.8	1
Female	155	19.9	1.21 (0.84; 1.72)	61.3	0.75 (0.54; 1.03)
Age group					
10–14 years	33	19.8	1	60.8	1
15–19 years	93	21.0	1.08 (0.70; 1.66)	67.1	1.32 (0.83; 2.11)
20–24 years	122	16.8	0.81 (0.51; 1.30)	62.1	1.06 (0.66; 1.70)
Maternal education					
High	141	20.5	1	64.1	1
Medium	47	22.0	1.08 (0.67; 1.73)	64.9	1.04 (0.71; 1.52)
Low	45	23.8	1.16 (0.77; 1.74)	59.6	0.82 (0.58; 1.17)
Unknown	15	15.4	0.75 (0.47; 1.20)	72.2	1.46 (0.90; 2.38)
Period					
Oct 2012–March 2013	59	19.8	1	64.6	1
April 2013–Sept 2013	82	20.6	1.04 (0.56; 1.95)	59.0	0.78 (0.44; 1.37)
Oct 2013–March 2014	86	23.6	1.19 (0.30; 4.78)	67.8	1.16 (0.46; 2.95)
April 2014–July 2014	21	17.9	0.9 (0.22; 3.67)	61.0	0.85 (0.16; 4.38)
Country					
Australia	24	15.9	1	66.8	1
Canada	22	19.1	1.26 (0.26; 6.11)	56.1	0.63 (0.21; 1.93)
France	25	24.7	1.75 (0.66; 4.65)	62.8	0.84 (0.37; 1.87)
Germany	19	8.3	0.48 (0.13; 1.81)	70.1	1.17 (0.43; 3.14)
Greece	12	20.8	1.40 (0.31; 6.25)	54.5	0.59 (0.11; 3.06)
Israel	27	19.4	1.28 (0.53; 3.10)	69.8	1.15 (0.53; 2.50)
Italy	31	19.0	1.25 (0.25; 6.38)	53.0	0.55 (0.19; 1.64)
Japan	4	36.2	3.03 (0.41; 22.71)	53.0	0.56 (0.17; 1.77)
Korea	14	35.4	2.93 (0.61; 14.19)	52.4	0.54 (0.18; 1.64)
New Zealand	9	32.6	2.59 (0.47; 14.35)	85.1	2.88 (0.50; 16.72)
Spain	28	9.8	0.57 (0.31; 1.06)	69.5	1.14 (0.60; 2.15)
The Netherlands	33	14.7	0.91 (0.49; 1.71)	66.5	0.99 (0.52; 1.86)

A Adjusted by gender, age group, mother educational level, period and country.

3.5. Contribution to variability of key cellular phone use characteristics

In keeping with the results presented above, country of origin was by far the largest contributor to the total variability for phone use characteristics: over 50% of the total variability for sent and received SMS, and almost 30% of the total variability for the number of calls, were accounted for by the country of origin (Fig. 1). Age and country accounted for approximately equal amounts (nearly 20% each) of the total variability for call duration. Gender, time period, and maternal education explained very little of the variability in phone use characteristics (Fig. 1).

3.6. Network communication protocols

Overall, UMTS (3G) was the most commonly used communication protocol with 37% of voice calls occurring using UMTS. HSDPA (3G transitional) was the next most common, with 32% of voice calls. UMTS was the most common communication protocol in Canada, France, Greece, Italy, and The Netherlands (80%, 30%, 36%, 41%, and 55%, respectively) (Fig. 2). In contrast, HSDPA was the most common network in Australia, Germany, Israel, Japan, New Zealand, and Spain (69%, 36%, 68%, 51%, 46%, and 33%, respectively). The most common network in Korea was “other” (43%). GPRS and EDGE (both 2G transitional) were not commonly used in any of the countries during our study period; use ranged from 0% (Japan and Korea) to 32% (The Netherlands) GPRS and 22% (France and Germany) EDGE, respectively.

In sensitivity analyses comparing the first week to subsequent weeks (allowing for a possible adaptation period) no differences were seen in any of the above results (results not shown). Furthermore, there were no substantial differences in phone use seen between volunteers using their own phones versus a study-provided phone.

4. Discussion

Mobi-Expo is the first study to describe the characteristics of cellular phone use among young people in 12 countries around the world using a software application. Results indicate that the number and duration of voice calls, as well as the number of SMS messages and the amount of data used, were mainly determined by country and age, and, to a lesser extent by sex, educational level, and calendar period. Laterality and hands-free use were less influenced by these user characteristics. Networks varied widely between countries, but a clear predominance of 3G over 2G network use was observed during the study period (2012–2014).

4.1. Voice calls

Number and duration of voice calls are the most used proxies of exposure to RF from mobile phone use. As RF exposure primarily comes from voice calls, it is important to understand what factors influence the number and duration of calls. Our results show that RF exposure may vary widely by country, as evidenced by the large differences in phone use seen among countries. Differences were seen by age as well: notably, the oldest age group had a higher number and duration of voice calls. Gender and social class were observed to have smaller effects, but our findings regarding higher talk time among girls and among lower social classes are in line with other recent studies in younger children (Guxens et al., 2016, Sudan et al., 2016). Although the calendar period of use was not statistically significantly associated with the number and duration of calls in this study, these characteristics tended to decrease over time. It is worth noting that the study periods were short (three to six months) in most of the participating countries.

In comparison with our findings, CEFALO, a study among 7–19 year old children and adolescents investigating possible associations between cellular phone use and brain tumors, had a much lower level of phone use among controls during a period from early 2004 through mid-2008 (Aydin et al., 2011). The top quartile of controls had a cumulative lifetime use of 2638 calls and 144 h spent on voice calls. Using the mean number and duration of calls, it would take the participants in our study less than three years to reach the lifetime use of the highest quartile of CEFALO controls. Recent analyses of the Danish national birth cohort show that of children who use a phone, almost 60% of the 11 year olds (data collected from mid-2010 to mid-2014) made less than one phone call per day, and typically spent between 1 and 4 min per phone call (Sudan et al., 2016). In contrast, the median number of phone calls made and received by volunteers in our 10–14 year old age category was 15.3 calls per week, which translates to roughly 2 calls per day. The median duration of voice calls in the youngest age group was 15.2 min, or approximately 1 min per call (results not shown). This is higher than Australian primary school children; Redmayne et al. (2016) found that fourth-grade students (aged 8 to 11 years) interviewed in 2011 made a median number of only 2.5 calls per week in that country.

4.2. SMS, cellular data, and Wi-Fi use

Mobi-Expo is the first study to describe the characteristics of SMS, cellular data, and Wi-Fi use among young people in a comparable way across countries. The results presented here indicate a wide variation in the use of SMS, data, and Wi-Fi between ages and countries. Spain and The Netherlands had the longest recruiting periods (October 2012 into early 2014); volunteers in these countries showed an increase in Wi-Fi use when comparing subjects' use at the end of the recruiting period compared to those at the beginning of the recruiting period. To date, there are few research results estimating the proportion of total RF exposure (to the brain or to other parts of the body) from SMS, cellular data, and Wi-Fi. In a Swiss study, adolescents reported cell phone use, cordless phone use, and gaming on various devices (e.g., laptops, tablets, etc.) (Roser et al., 2015).

4.3. Hands-free use and laterality

In Mobi-Expo, we observed very few differences in laterality of use and hands-free use according to study variables such as sex, age, maternal education, and country. We observed only small differences in hands-free usage between some countries. Only one small study previously assessed the validity of self-reported laterality among adolescents, and found a modest agreement with laterality as measured by hardware-modified phones (κappa = 0.3, 95% CI: 0.0, 0.6) (Inyang et al., 2010). In Mobi-Expo, we present a broader picture with actual percentages of total call time the phone was held on the right, left, and/or neither side of the head. These results provide important information for improving estimates of RF dose deposited in the brain. First, the handset is not near the head for the full call duration, but rather for about 83% of the time. In addition to intentional hands-free device or speaker phone usage, this is explained by other hands-free use such as answering and ending a call. Furthermore, the time spent with the phone on one side of the head was not as high as the 90% assigned to the self-reported predominant side within the RF dose algorithm used in the INTERPHONE study (Cardis et al., 2011a), but that was a study of older adults. Although the SMSP-recorded laterality could be incorrect when subjects are not in the upright position during a call (Goedhart et al., 2015), we expect the errors to be small due to that unusual position, and to work in both directions (left to right and vice versa). Although only certain phone types were included in the laterality analyses, this study provides important information on both use of hands-free and laterality among volunteers in multiple countries and across a relative wide age range. The Mobi-Expo laterality measurements can be used to obtain more realistic estimates of RF exposure to both sides of the head in epidemiological studies on cellular phone use and brain tumor risk in young people.

4.4. Network communication protocols

The communication system used for phone calls is important for estimating the RF energy absorbed in the brain as the phone's output power differs by communication protocol (Cardis et al., 2011b). The XMobiSense application used in Mobi-Expo provides a crude, but useful, estimate of how frequently each communication system is used within a different country and/or region. Results show that although most volunteers registered some use of GPRS and EDGE networks, UMTS and HSDPA were the most common networks across countries. There were large differences between countries in the types of networks used.

4.5. Strengths and limitations

This is the first study to collect comparable data on cellular phone use among young people in 12 countries worldwide, providing valuable insight into how they use their cellular phones as well as important insights for future and ongoing epidemiological studies. Although only certain phone types were included in the laterality analyses, this study provides important information on both use of hands-free and laterality among volunteers in multiple countries and across a relatively wide age range. Further, using an application installed on a phone provides a much more complete picture of phone usage (including exact number of calls, duration, and laterality) than operator records.

A major limitation of this study is that it is a convenience sample, limiting the generalizability of the results. Given that most of the volunteers were found through friends and/or colleagues of the research team, the education level and in turn socioeconomic status is likely higher than that of the general population. Although the sample size is too small in this study, considering effect modification may provide further insight into exposure characteristics between countries. Providing phones to volunteers could result in a change of regular use during the monitoring period; however, in analyses comparing the first week to subsequent weeks (allowing for a possible adaptation period) no differences were seen (results not shown). Furthermore, there were no significant differences in phone use seen between volunteers using their own phones versus a study-provided phone. Thus, it does not seem that there is a change in use based on a volunteer using a study-provided phone.

5. Conclusions

This study across 12 countries shows that a large part of the variance in phone use characteristics such as call number and duration, and data and Wi-Fi use is explained by a cell phone user's age and country. Differences were also observed by gender, education and study period but these explained a much smaller part of the variance. Laterality and hands-free use are hardly influenced by these user characteristics. Although limited by a convenience sample, these results will provide valuable insights to the design, analysis, and interpretation stages of future epidemiological studies concerning the health effects of exposure resulting from cellular phone use in children, adolescents and young people. Further, should RF be found to have health impacts, then these findings would be of use in designing strategies to reduce mobile phone use.

Conflict of interest

JW works for the research center of France Telecom. Canada (Ottawa) received financial support from the Canadian Wireless Telecommunications Association under the federal university-industry research partnerships noted below. The rest of the authors declare no conflict of interest.

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