Bioelectromagnetics 36:538–543 (2015)

Letter to the Editor

Using Software-Modified Smartphones to Validate Self-Reported Mobile Phone Use in Young People: A Pilot Study

Geertje Goedhart,[1]* Martine Vrijheid,[2,3,4] Joe Wiart,[5] Martine Hours,[6] Hans Kromhout,[1] Elisabeth Cardis,[2,3,4] Chelsea Eastman Langer,[2,3,4] Patricia de Llobet Viladoms,[2,3,4] Amelie Massardier-Pilonchery,[6] and Roel Vermeulen[1]

[1]Department of Environmental Epidemiology, Utrecht University, Institute for Risk Assessment Sciences (IRAS), Utrecht, The Netherlands
[2]Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
[3]Biomedical Research Centre Network for Epidemiology and Public Health (CIBERESP), Barcelona, Spain
[4]Universitat Pompeu Fabra (UPF), Barcelona, Spain
[5]Whist Lab, Institute Mines-Télécom/Orange, Paris, France
[6]Epidemiological Research and Surveillance Unit in Transport, Occupation and Environment (UMRESTTE), Université de Lyon/The French Institute of science and technology for transport, development and networks (IFSTTAR), Lyon, France

A newly developed smartphone application was piloted to characterize and validate mobile phone use in young people. Twenty-six volunteers (mean age 17.3 years) from France, Spain, and the Netherlands used a software-modified smartphone for 4 weeks; the application installed on the phone recorded number and duration of calls, data use, laterality, hands-free device usage, and communication system used for both voice calls and data transfer. Upon returning the phone, participants estimated their mobile phone use during those 4 weeks via an interviewer-administered questionnaire. Results indicated that participants on average underestimated the number of calls they made, while they overestimated total call duration. Participants held the phone for about 90% of total call time near the head, mainly on the side of the head they reported as dominant. Some limitations were encountered when comparing reported and recorded data use and speaker use. When applied in a larger sample, information recorded by the smartphone application will be very useful to improve radiofrequency (RF) exposure modeling from mobile phones to be used in epidemiological research. Bioelectromagnetics. 36:538–543, 2015.

Key words: laterality; mobile application; adolescent; child; validation study

Epidemiological studies on health effects of mobile phone use suffer from inaccurate exposure assessment, that is, participants' self-reported mobile phone use [Auvinen et al., 2006; Vrijheid et al., 2006b; Morrissey, 2007; Inyang et al., 2008; Aydin et al., 2011a; Cardis et al., 2011b]. Validation studies with operators' traffic records or software-modified phones in adults [Parslow et al., 2003; Samkange-Zeeb et al., 2004; Vrijheid et al., 2006a, 2009], and more recently in children and adolescents [Inyang et al., 2009; Aydin et al., 2011b], have shown that recall of number and duration of mobile phone calls was prone to systematic and random errors. Accuracy of other determinants used in radiofrequency (RF) exposure models from mobile phones, such as later-

Grant sponsors: Netherlands Organisation for Health Research and Development (ZonMw), The Hague, The Netherlands; (85500022, 85800001); French Agency for Food, Environmental and Occupational Health & Safety (ANSES) (N°2011/1/216).

Conflicts of interest: None.

*Correspondence to: Geertje Goedhart, Department of Environmental Epidemiology, Utrecht University, Institute for Risk Assessment Sciences, PO Box 80178, 3508 TD Utrecht, The Netherlands. E-mail: g.goedhart@uu.nl

Received for review 22 August 2014; Accepted 22 June 2015

DOI: 10.1002/bem.21931
Published online 30 July 2015 in Wiley Online Library (wileyonlinelibrary.com).

ality and the use of hands-free devices [Cardis et al., 2011a], have not been adequately measured yet. As part of Mobi-Kids [Sadetzki et al., 2014], a large ongoing international study exploring the potential association between communication technology, other environmental risk factors, and risk of brain tumors in young people (http://www.mbkds.com), Mobi-Expo was planned as a validation study to characterize and validate mobile phone use habits in young people from all participating countries using software-modified smartphones (SMSP). The SMSP had a newly developed software application (app) installed that recorded frequency and duration of calls, laterality, use of hands-free devices, and data use. The Mobi-Expo protocol and the SMSP were piloted in children and adolescents in three countries.

Between January and June 2012, 26 young people were recruited in France, Spain, and the Netherlands (NL). Only people who currently used a mobile phone (at least once a week) were eligible. Because of valuable equipment used, volunteers were selected from colleagues and acquaintances. The National Committee on Information Technology and Liberties, France, and the Parc de Salut-Mar Ethics Committee, Spain approved the study. In NL, medical ethical approval was not required for this study. All study volunteers (as well as parents for volunteers <18 years) signed informed consent forms before participating. After completing a screening questionnaire, participants transferred their subscriber identity module (SIM) card to the study-provided SMSP. Participants were instructed to use the SMSP for 4 weeks as they would use their own mobile phone. Upon returning the SMSP, participants completed a short interview, either face-to-face ($n = 23$) or by phone within the next week ($n = 3$), concerning any changes in and an estimate of their mobile phone use during the 4-week period of SMSP use. This included number and duration of calls made and received; laterality (side of head where they generally held the handset: right, left, or both); use of hands-free devices (i.e., headset, speaker phone, hands-free kit in vehicle); time spent using the Internet; and whether other people had used their SMSP.

The SMSP contained the app "XMobiSense" developed by Whist Lab, the common lab of the Institute Mines-Télécom and Orange (Paris, France). The app recorded the following: date and time of voice calls, communication system used (second [2G] or third generation [3G] mobile telecommunications technology: General Packet Radio Service [GPRS, 2.5G], Enhanced Data Rates for GSM Evolution [EDGE, 2.75G], Universal Mobile Telecommunications System [UMTS, 3G], High-Speed Downlink Packet Access [HSDPA, 3.5G], and "other" systems), laterality during a voice call (amount of call time phone was held, either solely or combined, at right or left side of head, or away from the head, i.e., using a hands-free device or "speaker use"), and transmitted and received data using 2G/3G or Wi-Fi (kilobytes [kB] per day). As "speaker use" was recorded when the handset was not near the head during a voice call (and no hands-free device was connected)—using the built-in capacity of the smartphone to turn off the screen when close to the head—speaker use includes more than using the speaker mode of the phone, for example, answering/ending a voice call. The app was extensively tested in Spain and NL. Number and duration of calls and headset usage were accurate, but some errors were found for laterality. As laterality is based on values from the phone accelerometer (a combination of three axes determine the angle to which the handset is held), with the assumption that the participant is mostly in the vertical position during phone use, scenarios where the user was in a more horizontal position gave some erroneous laterality values.

The mean age of participants was 17.3 years (range 11–23 years); 54% were female. Just over 80% of the participants reported that their mothers were graduates of university/high-level technical school or higher. Seventeen (65%) participants reported a change in mobile phone use while using the SMSP compared to their own phone. Increased data use was most often reported, followed by a change in number and/or duration of calls. No change in laterality was reported. Per week, the participants made on average 19 calls (standard deviation [SD] = 13.2), spoke on the phone for 30.4 min (SD = 28.8), and transferred 329.6 megabytes (MB) (SD = 320.6) of data (Table 1). No significant differences in these variables were found between the 4 weeks of SMSP use applying Analysis of variance (ANOVA) with repeated measures, neither when specifically comparing the first week of use (we hypothesized there might be an "adaptation" period) with the second to fourth weeks (paired-samples *t*-tests: number of calls week 1 vs. weeks 2–4: $P = 0.91$; call duration: $P = 0.36$; data transfer: $P = 0.51$). ANOVA analyses showed that average number of calls and call duration increased statistically significantly with increasing age ($P = 0.03$, <0.01, respectively). Data use was higher among males compared to females ($P = 0.06$). Participants from France had, on average, a higher number and duration of calls than participants from Spain and NL, while their weekly data transfer was lower (although not statistically significant). The communication system used most often for voice calls in NL

TABLE 1. SMSP-Recorded Mobile Phone Use, Stratified by Age, Gender, and Country

	N	Number of calls (mean p/wk)	Call duration (mean min p/wk)	Data use (mean MB p/wk)
Total sample	26	19.0	30.4	329.6
By age				
10–14 years	7	10.0	10.4	321.3
15–19 years	10	18.1	24.8	433.5
20–24 years	9	26.9	52.3	220.8
By gender				
Male	12	17.8	24.4	458.0
Female	14	19.9	35.6	219.6
By country				
NL	11	11.9	23.3	358.6
Spain	8	22.8	33.7	389.4
France	7	25.7	37.8	215.8

and France was UMTS (82.1% and 47.5% of total call time, respectively), while GPRS was most common in Spain (35.7%) (Fig. 1). Data were mostly transferred via Wi-Fi (93.0%) rather than 2G/3G networks (Fig. 2); Wi-Fi use was lower in France (75.9%) compared to Spain (94.1%) and NL (96.9%).

Spearman correlation coefficients between SMSP-recorded and self-reported number and duration of calls and data use were 0.75, 0.77, and 0.59, respectively (Fig. 3). On average, participants seemed to underestimate number of calls made and received (geometric mean ratio of self-reported to SMSP-recorded = 0.65, 95% confidence interval (CI) 0.50–0.85). SMSP-recorded calls, however, also included unsuccessful outgoing calls (i.e., no connection); when excluding outgoing calls of 0–2 s (potentially unsuccessful calls, $n = 120$), the geometric mean ratio increased to 0.68, 95%CI 0.53–0.89. Total call duration was on average overestimated by participants (geometric mean ratio = 1.71, 95%CI 1.28–2.30).

SMSP-recorded laterality, hands-free device, and speaker use were adjusted for total call duration. Participants held the phone near the head for about 90% of total call time (Table 2). Participants who reported generally using the phone on the right side of their head did so on average for 63.8% (95%CI 54.2–73.4%) of total call time as recorded by the SMSP. Self-reported left-side users held the phone on average for 76.9% (95%CI 61.1–92.7%) of total call time on the left side of their head. For the one participant reporting headset use, the SMSP did not record hands-free device usage, while for the non-headset-users, the SMSP recorded hands-free usage for an average of 0.5% (95%CI 0.0–1.1%) of total call time. At least a small amount of "speaker use" (median 2.4 s/call) was recorded by the SMSP for all participants, probably recorded when answering/ending a call. Whether the observation that the percentage of recorded speaker use was on average slightly lower among participants who reported using the phone's speaker mode (9.1%) compared to non-users (10.5%) is due to misreporting or the way the app measured speaker use remains therefore unclear.

This pilot study presented early indications on valuable information provided by the smartphone app, which can be used to improve RF exposure

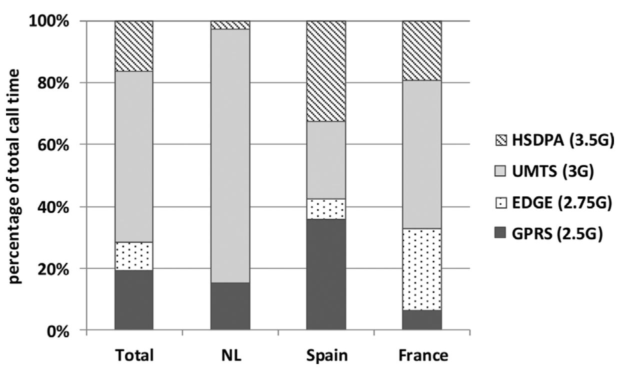

Fig. 1. Communication systems used for voice calls, stratified by country.

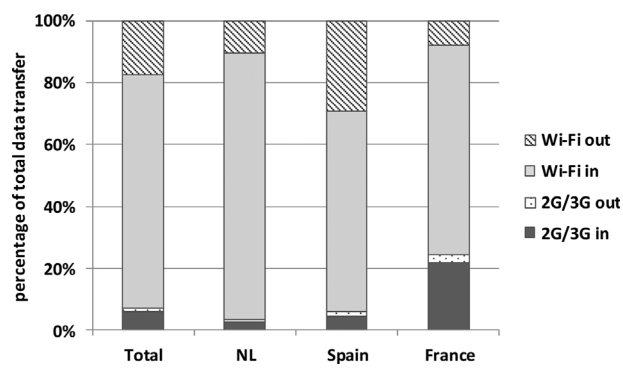

Fig. 2. Data transfer made over 2G/3G networks or Wi-Fi, stratified by country.

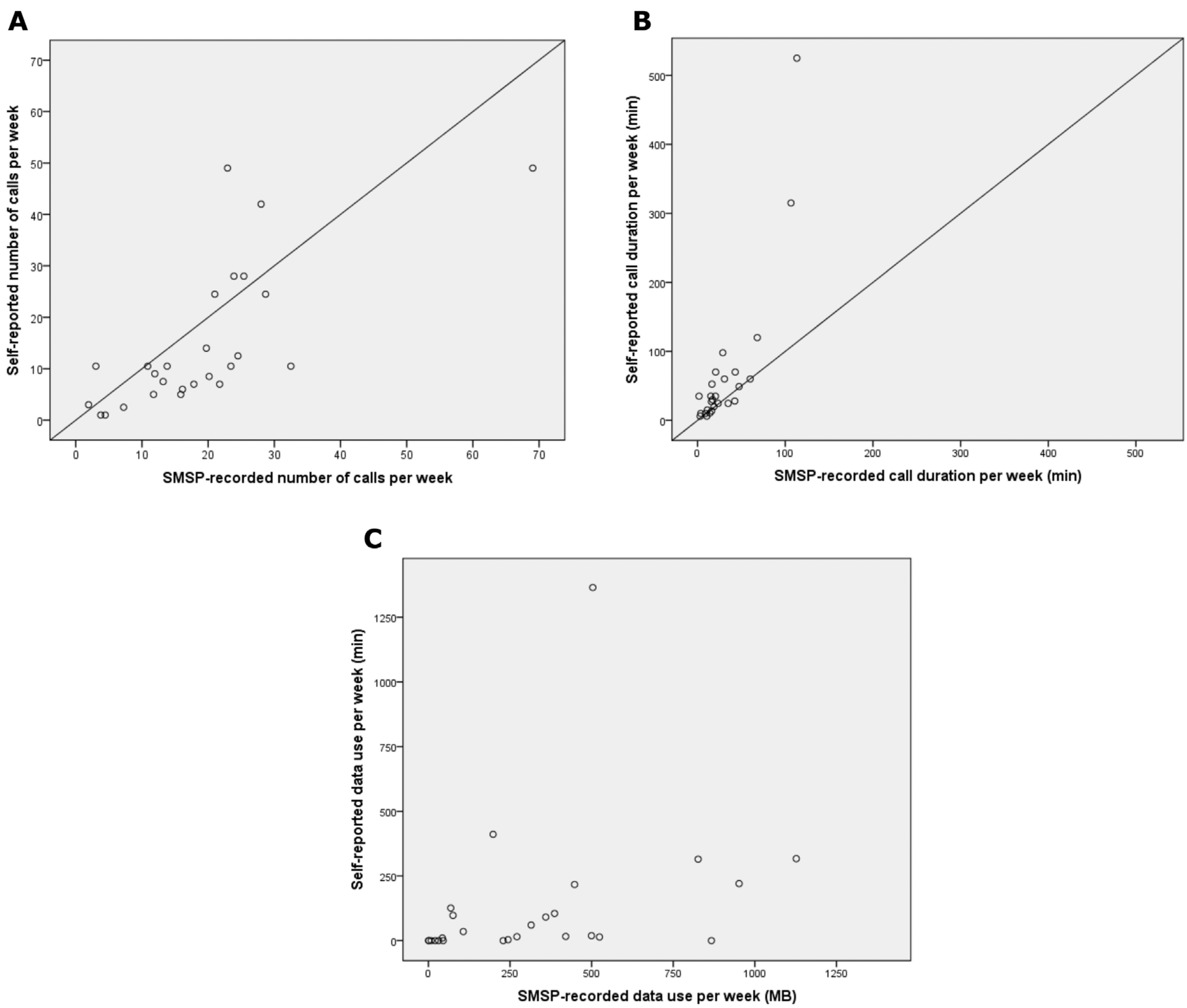

Fig. 3. Scatter plot of self-reported versus SMSP-measured number of calls/week (**A**), duration of calls in minutes/week (**B**), and data use in minutes/week versus MB/week (**C**); solid line denotes line of equality.

models utilizing self-reported mobile phone use. Number and duration of voice calls are important determinants as they are most frequently used as proxy for RF dose in the brain [Cardis et al., 2011b]. While an overestimation of call duration was consistently observed in previous validation studies, both over- and underestimations of number of calls have been observed [Parslow et al., 2003; Samkange-Zeeb et al., 2004; Vrijheid et al., 2006a, 2009; Inyang et al., 2009; Aydin et al., 2011b]. Such estimates of random and systematic recall errors can be used in sensitivity analyses to examine the impact of recall errors on the main risk estimates in epidemiological studies on mobile phone use and brain tumors, including the ongoing Mobi-Kids study [Vrijheid et al., 2006b; Aydin et al., 2011a]. Other important determinants used in RF exposure models from mobile phones are laterality and hands-free usage. Only one small previous study assessed the validity of self-reported laterality among adolescents, and found modest agreement with laterality as measured by hardware-modified phones ($\kappa = 0.3$) [Inyang et al., 2010]. In this study, we presented a broader picture with actual percentages of total call time the phone was held at the right, left, and/or neither side of the head. These pilot results provided important suggestions to improve estimated RF dose in the brain. First, the handset is not near the head for full call duration, but rather about 90% of the time. This seems to be primarily explained by answering and ending a call rather than actively using a hands-free kit or speaker mode. Furthermore, on average,

TABLE 2. Laterality, Headset, and Speaker Use; Self-Report Versus SMSP-Recorded

	SMSP-recorded laterality (mean % (95%CI) of total call time)			
Self-reported laterality	*N* (%)	Right side	Left side	Away from the head
Mainly right side	20 (76.9)	63.8 (54.2–73.4)	25.0 (15.8–34.3)	11.2 (7.8–14.6)
Mainly left side	4 (15.4)	16.2 (1.3–31.1)	76.9 (61.1–92.7)	6.9 (2.8–11.0)
Both sides	2 (7.7)	38.1 (35.9–40.3)	50.4 (39.0–61.8)	11.5 (2.4–20.7)
Total	26 (100)	54.5 (44.2–64.8)	34.9 (24.4–45.4)	10.6 (7.8–13.4)

	SMSP-recorded headset use	
Self-reported headset use	*N* (%)	Mean % (95%CI) of total call time
No	25 (96.2)	0.5 (0.0–1.1)
Yes	1 (3.8)	0.0 (–)
Total	26 (100)	0.5 (0.0–1.1)

	SMSP-recorded speaker use	
Self-reported speaker use	*N* (%)	Mean % (95%CI) of total call time
No	19 (73.1)	10.5 (7.1–13.9)
Yes	7 (26.9)	9.1 (5.5–12.7)
Total	26 (100)	10.1 (7.5–12.7)

participants used the handset more on the side of the head they reported, but this percentage was not as high as the 90% assigned to the predominant side within the RF dose algorithm used in the INTERPHONE study [Cardis et al., 2011a]. Although SMSP-recorded laterality could be false when subjects are not in the upright position during calling, we expect errors due to the unusual position to be small, and to be working in both directions (left to right and vice versa). Laterality measurements from a larger sample are required to estimate a more realistic exposure to both sides of the head. These could be used in epidemiological studies on mobile phone use and brain tumor risk [Frederiksen et al., 2012]. The communication system used for phone calls is important for estimating the RF energy absorbed in the brain because the phone's output power differs by communication protocol [Cardis et al., 2011b]. When applied to a larger sample, the app can provide a crude but useful estimate on how frequently each communication system is used within a different country and/or region. SMSP-recorded data transfer could not be used to clarify accuracy of self-reported data use, as SMSP recorded quantity of data transferred (in kB) whereas the participants reported time spent using the Internet on the mobile phone.

As this pilot study is limited by a small convenient sample and a very short interval between SMSP use and self-reported mobile phone use, more extensive analyses will be done with data collected in the full Mobi-Expo validation study. Furthermore, as the app can be used on any regular smartphone running under the Android operating system, in the full study we will include participants who install the app on their own Android smartphone. This has the advantage that mobile phone use behavior of these participants will be less likely to change during data collection. Besides direct application of the app XMobiSense for mobile phone use validation studies, this study shows how software applications in general could be used in large population-based studies to collect exposure data.

ACKNOWLEDGMENTS

The authors thank Thierry Sarrebourse and Emmanuelle Conil (Whist Lab, France) for their technical support with the software application XMobiSense.

REFERENCES

Auvinen A, Toivo T, Tokola K. 2006. Epidemiological risk assessment of mobile phones and cancer: Where can we improve? Eur J Cancer Prev 15:516–523.

Aydin D, Feychting M, Schüz J, Andersen TV, Poulsen AH, Prochazka M, Klaeboe L, Kuehni CE, Tynes T, Röösli M. 2011a. Impact of random and systematic recall errors and selection bias in case-control studies on mobile phone use and brain tumors in adolescents (CEFALO study). Bioelectromagnetics 32:396–407.

Aydin D, Feychting M, Schüz J, Andersen TV, Poulsen AH, Prochazka M, Klaeboe L, Kuehni CE, Tynes T, Röösli M. 2011b. Predictors and overestimation of recalled mobile phone use among children and adolescents. Prog Biophys Mol Biol 107:356–361.

Cardis E, Armstrong BK, Bowman JD, Giles GG, Hours M, Krewski D, McBride M, Parent ME, Sadetzki S, Woodward A, Brown J, Chetrit A, Figuerola J, Hoffmann C, Jarus-Hakak A, Montestruq L, Nadon L, Richardson L, Villegas R, Vrijheid M. 2011a. Risk of brain tumours in relation to estimated RF dose from mobile phones: Results from five Interphone countries. Occup Environ Med 68:631–640.

Cardis E, Varsier N, Bowman JD, Deltour I, Figuerola J, Mann S, Moissonnier M, Taki M, Vecchia P, Villegas R, Vrijheid M, Wake K, Wiart J. 2011b. Estimation of RF energy absorbed in the brain from mobile phones in the Interphone study. Occup Environ Med 68:686–693.

Frederiksen K, Deltour I, Schuz J. 2012. Estimating associations of mobile phone use and brain tumours taking into account laterality: A comparison and theoretical evaluation of applied methods. Stat Med 31:3681–3692.

Inyang I, Benke G, McKenzie R, Abramson M. 2008. Comparison of measuring instruments for radiofrequency radiation from mobile telephones in epidemiological studies: Implications for exposure assessment. J Expo Sci Environ Epidemiol 18:134–141.

Inyang I, Benke G, Morrissey J, McKenzie R, Abramson M. 2009. How well do adolescents recall use of mobile telephones? Results of a validation study. BMC Med Res Methodol 9:36.

Inyang I, Benke G, McKenzie R, Wolfe R, Abramson MJ. 2010. A new method to determine laterality of mobile telephone use in adolescents. Occup Environ Med 67:507–512.

Morrissey JJ. 2007. Radio frequency exposure in mobile phone users: Implications for exposure assessment in epidemiological studies. Radiat Prot Dosimetry 123:490–497.

Parslow RC, Hepworth SJ, McKinney PA. 2003. Recall of past use of mobile phone handsets. Radiat Prot Dosimetry 106:233–240.

Sadetzki S, Langer CE, Bruchim R, Kundi M, Merletti F, Vermeulen R, Kromhout H, Lee AK, Maslanyj M, Sim MR, Taki M, Wiart J, Armstrong B, Milne E, Benke G, Schattner R, Hutter HP, Woehrer A, Krewski D, Mohipp C, Momoli F, Ritvo P, Spinelli J, Lacour B, Delmas D, Remen T, Radon K, Weinmann T, Klostermann S, Heinrich S, Petridou E, Bouka E, Panagopoulou P, Dikshit R, Nagrani R, Even-Nir H, Chetrit A, Maule M, Migliore E, Filippini G, Miligi L, Mattioli S, Yamaguchi N, Kojimahara N, Ha M, Choi KH, Mannetje A', Eng A, Woodward A, Carretero G, Alguacil J, Aragones N, Suare-Varela MM, Goedhart G, Schouten-van Meeteren AA, Reedijk AA, Cardis E. 2014. The MOBI-kids study protocol: Challenges in assessing childhood and adolescent exposure to electromagnetic fields from wireless telecommunication technologies and possible association with brain tumor risk. Front Public Health 23:124.

Samkange-Zeeb F, Berg G, Blettner M. 2004. Validation of self-reported cellular phone use. J Expo Anal Environ Epidemiol 14:245–248.

Vrijheid M, Armstrong BK, Bédard D, Brown J, Deltour I, Iavarone I, Krewski D, Lagorio S, Moore S, Richardson L, Giles GG, McBride M, Parent ME, Siemiatycki J, Cardis E. 2009. Recall bias in the assessment of exposure to mobile phones. J Expo Sci Environ Epidemiol 19:369–381.

Vrijheid M, Cardis E, Armstrong BK, Auvinen A, Berg G, Blaasaas KG, Brown J, Carroll M, Chetrit A, Christensen HC, Deltour I, Feychting M, Giles GG, Hepworth SJ, Hours M, Iavarone I, Johansen C, Klaeboe L, Kurttio P, Lagorio S, Lönn S, McKinney PA, Montestrucq L, Parslow RC, Richardson L, Sadetzki S, Salminen T, Schüz J, Tynes T, Woodward A. 2006a. Validation of short term recall of mobile phone use for the Interphone study. Occup Environ Med 63:237–243.

Vrijheid M, Deltour I, Krewski D, Sanchez M, Cardis E. 2006b. The effects of recall errors and of selection bias in epidemiologic studies of mobile phone use and cancer risk. J Expo Sci Environ Epidemiol 16:371–384.