ORIGINAL ARTICLE

Validating self-reported mobile phone use in adults using a newly developed smartphone application

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ABSTRACT

Objective Interpretation of epidemiological studies on health effects from mobile phone use is hindered by uncertainties in the exposure assessment. We used a newly developed smartphone application (app) to validate self-reported mobile phone use and behaviour among adults.

Methods 107 participants (mean age 41.4 years) in the Netherlands either downloaded the software app on their smartphone or were provided with a study smartphone for 4 weeks. The app recorded the number and duration of calls, text messages, data transfer, laterality and hands-free use. Self-reported mobile phone use was collected before using the app and after 6 months through an interviewer-administered questionnaire.

Results The geometric mean ratios (GMR, 95% CI) and Spearman correlations (r) of self-reported (after 6 months) versus recorded number and duration of calls were: GMR=0.65 (0.53 to 0.80), r=0.53; and GMR=1.11 (0.86 to 1.42), r=0.57 respectively. Participants held the phone on average for 86% of the total call time near the head. Self-reported right side users held the phone for 70.7% of the total call time on the right side of the head, and left side users for 66.2% on the left side of the head. The percentage of total call time that the use of hands-free devices (headset, speaker mode, Bluetooth) was recorded increased with increasing frequency of reported hands-free device usage.

Discussion The observed recall errors and precision of reported laterality and hands-free use can be used to quantify and improve radiofrequency exposure models based on self-reported mobile phone use.

What this paper adds

- ▸ How much weight is given to the findings of epidemiological studies on health effects from mobile phone use depends to a large extent on how well these studies can account for inaccuracies in their exposure assessment, that is, self-reported mobile phone use.
- ▸ A newly developed smartphone application was used to record actual mobile phone use, enabling validation of self-reported phone use. In addition to the frequency and duration of phone calls, laterality, use of hands-free devices and data transfer were recorded by the application.
- ▸ Consistent with previous observations among adults, duration of calls was on average overestimated, while the number of calls was underestimated.
- ▸ Laterality data recorded by the application suggested that there is considerable within-person variability at the side of the head the phone is used, and in the percentage of call time the phone was actually near the head during voice calls.
- ▸ The observed recall errors and precision of reported laterality and hands-free use can be used to quantify and improve radiofrequency exposure models based on self-reported mobile phone use.

INTRODUCTION

One of the limitations of epidemiological studies exploring the possible health effects of radiofrequency (RF) emissions from mobile phones is their exposure assessment, that is, the studies rely largely on participants' self-reported frequency and duration of phone use.[1–5] How much weight is given to the findings of these epidemiological studies depends to a large extent on how well the studies can account for inaccuracies and potential bias in self-reported mobile phone use.

Several studies have been performed to validate recall of mobile phone use among adults, by comparing with operator records, or by using hardware-modified or software-modified phones (HMP, SMP).[2 6–9] The use of operator records is, however, often limited by incomplete records (eg, no information on incoming calls), or the inability to correct for shared phone users, prepaid users or business-phone users.[2] Moreover, these validation studies did not collect data on laterality and/or the use of hands-free devices, two important determinants of RF dose in the brain, used in studies on brain tumour risk. A potential risk from RF is expected to exist primarily on the side of the head where the phone is usually held (ipsilateral exposure) and, to a lesser extent, at the opposite side of the head (contralateral exposure).[10 11] Whether people can accurately recall the side of the head they generally held their phone is yet unknown. Furthermore, no information is available on the percentage of call time that people use hands-free devices (ie, lower exposure to the brain).

We used a newly developed software application (app) to validate self-reported mobile phone use among adults. The software app is installed on regular smartphones and records actual phone use, including the frequency and duration of calls, laterality, use of hands-free devices and data transfer.

METHODS

Study sample and design

Between April 2013 and January 2014, a total of 107 adults were recruited in the Netherlands through colleagues and acquaintances, and through a national website for recruitment of study participants (offering a small incentive to stimulate participants from various socioeconomic backgrounds). Extra efforts were made to recruit males and older participants. To be eligible to participate, participants had to use a mobile phone on average at least once a week. Participants signed an informed consent form before participating in the study. The Institutional Review Board of Utrecht University Medical Center confirmed that the study did not require approval according to the Dutch law.

To record data on actual mobile phone use, a newly developed software app called 'XMobiSense' was used in this study. As this app could only be installed on smartphones working under the Android operating system, we had two groups of participants: 'Android users' and 'non-Android users'. Android users (n=89) were participants who owned a smartphone operating under the Android system. The app was sent to them by e-mail to be installed on their smartphone. Non-Android users were participants who did not have a smartphone (n=13) or who had a smartphone working under another operating system (n=5). They were provided with a study phone, a regular smartphone (Samsung Galaxy SII) with the app already installed on it. Non-Android users were asked to use the study phone instead of their own mobile phone by transferring their SIM card to the study phone; they were further asked to use the study phone in a similar way as they would use their own mobile phone. After 4 weeks of data recording by the app, participants either returned the study phone (non-Android users) or were asked to create and send a zip file with the recorded data (Android users) to the study coordinator.

Self-reported mobile phone use

Before using the app, participants completed a baseline questionnaire (Q1, 0 months) containing sociodemographic questions and current mobile phone use. After the 4 weeks of data recording by the app, non-Android users completed a change-of-use questionnaire when returning the study phone (Q2, 1 month), in which they were asked whether and, if so, how, their phone use had changed while using the study phone compared to their regular mobile phone use. Six months after using the app, all participants were contacted again to complete a short interview either face to face (n=26) or by phone (n=77) (Q3, 6 months). The purpose of the interview (ie, recall 6 months back) was not indicated beforehand. Participants were asked to make an estimation of their mobile phone use during the 4-week period of data recording by the app: the number and duration of calls they made and received, on which side of the head they were generally (more than half of the time) holding the phone during voice calls (right, left or both), use of hands-free devices (car kit, (Bluetooth) headset, speaker function of the phone), number of text messages sent, time spent using the Internet (eg, sending WhatsApp/Ping messages, sending e-mail or files, surfing the internet, downloading music/movies, online games, VoIP use) and whether other people used the phone for voice calls or data use. The Q1 and Q3 questionnaires were based on the mobile phone part of the questionnaire developed and used within the MOBI-Kids study, a multinational case–control study investigating the potential effects of childhood and adolescent exposure to electromagnetic fields from mobile communications technologies on brain tumour risk.[12]

Recorded mobile phone use

The software app 'XMobiSense' was developed by the WHIST Lab, the common lab of Institut Mines Telecom and Orange labs, Paris, France, to record data on actual mobile phone use. The app can be installed on any regular smartphone working under the Android operating system. The following information was recorded by the app: date and time of incoming and outgoing voice calls, the laterality of use during voice calls (seconds per call: right side, left side, use of hands-free devices (headset (wired), speaker mode, Bluetooth (headset or car kit)) and 'other hands-free usage' (eg, holding the phone away from the head to answer or end a call)), number of text messages sent and received per day, the quantity (in kilobytes, kB) of transmitted and received data per day, and the type of network used for voice calls and data transfer. The app did not record any personal information, such as contact persons or websites visited. Participants could not see which data the app was recording.

The app is currently also used within the multinational Mobi-Expo study, a validation study on self-reported mobile phone use among young people, as part of the MOBI-Kids study.[13] In collaboration with CREAL (Barcelona, Spain), the app was extensively tested using 10 frequently used phone models. The number and duration of calls and hands-free device usage were accurately measured independently of the phone model, but some errors were found for laterality (right/left side) and 'other hands-free usage'. As laterality is based on values from the accelerometer of the phone (a combination of three axes determine the angle at which the phone 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 while calling (eg, laying on the couch) gave some erroneous laterality values. We could, however, not account for this in the analyses, as we did not know the position of the participants when they were calling. 'Other hands-free usage' was recorded by the app when during a voice call the phone was not near the head and no hands-free device was connected, based on values from the proximity sensor of the phone. The tests, however, pointed out that some phone models gave exceptional high values for 'other hands-free usage', probably due to limited performance of the proximity sensor of those models in cooperation with the app. Therefore, in the analyses on laterality and hands-free device usage, only participants (n=56) with a phone model that accurately performed in the tests (Samsung Galaxy S (Plus), S2, S3 (mini), S4 (mini), Ace) were included.

Statistical analysis

Participants with no (n=5) or less than 3 weeks (n=6) of data recorded by the app were excluded from the analyses, leaving a final sample of 96 participants for the analyses. For participants with a long period of data recording (n=5), data were truncated at 6 weeks.

The recorded and self-reported number of voice calls was calculated per week, and the duration of calls in minutes per week. Recorded outgoing calls included both successful and unsuccessful (ie, no connection) calls, while the self-reported information most likely only included the successful calls. Sensitivity analyses were performed to explore the impact of excluding recorded outgoing calls of 10 s or less (potentially unsuccessful). Recorded data transfer was calculated in megabytes (MB) per week, while self-reported total time spent using the Internet was calculated in minutes per week. The recorded variables laterality (right/left side), hands-free device usage and 'other hands-free usage' were recalculated from seconds per call to percentage over the total call time, thereby accounting for call duration. Self-reported hands-free device users were divided into low ('almost never or rarely'; 'less than half the time') and high ('about half the time'; 'more than half the time'; '(almost) always') frequency users.

Descriptive statistics and analysis of covariance (ANCOVA) were performed to explore the recorded mobile phone use by age and gender. To examine whether the first week of data collection by the app was different from the second to fourth week (we hypothesised that there might be an 'adaptation' period), repeated measures analysis of variance, applying the Greenhouse-Geisser correction and paired-samples t tests were performed to account for multiple measurements within one participant. The agreement between self-reported (after 6 months) and recorded number and duration of calls was explored with Bland-Altman plots, plotting the relative difference between self-reported and recorded information against the reported information (log transformed), Spearman correlations and geometric mean ratios (GMR; the ratios of self-reported to recorded number and duration of calls were log-transformed; then the mean and 95% CIs were calculated and exponentiated to the arithmetic scale). The GMRs were stratified by the covariates age, gender, educational level, type of phone user (study vs own phone) and level of phone use; statistical significant differences were explored with ANCOVA. Self-reported number and duration of calls at baseline (ie, before using the app) were also compared to recorded number and duration of calls by calculating the GMRs. The agreement between self-reported (after 6 months; in minutes) and recorded (MB) data use was explored with the use of a scatterplot and Spearman correlation. Self-reported (after 6 months) and recorded laterality and hands-free device usage were compared using crosstabs. Data were analysed using SPSS V.20.0 (SPSS Inc, Chicago, Illinois, USA).

RESULTS

The mean age of the participants was 41.4 years (range 25–66 years); of them, 38.3% were male, and 78% were graduates of higher professional/university education. Of the 18 participants who used a study phone, 13 (72.2%) reported a change in their mobile phone use while using the study phone compared to their regular mobile phone. The change most often reported (69.2%) was increased data use (eg, surfing the Internet). An increase in the number of calls and call duration was reported by three and two participants, respectively. No change in laterality was reported.

To determine whether the first week of data collection by the app differed from the second to fourth week, we first explored whether there were any differences in the number and duration of calls between the 4 weeks of data collection. No significant differences were found for the number of calls ($p=0.23$) and call duration ($p=0.21$). Specific analyses comparing the first week of use with the second to fourth week also did not show statistically significant differences: average (SD) number of calls in week 1, 17.3 (18.9), versus weeks 2–4, 16.7 (14.3) ($p=0.59$), and average call duration in week 1, 51.6 min (73.9), versus weeks 2–4, 47.5 min (53.6) ($p=0.38$). Further analyses were therefore performed on the full data set, including the first week of data collection.

In total, 6869 calls were monitored by the app. Per week, the participants made on average (SD) 16.1 (14.4) calls, spoke on the phone for 47.5 (56.1) minutes, sent and received 12.4 (10.2) text messages and transferred 435.6 (902.1) MB. Table 1 presents the mobile phone use patterns by age group and gender. The average call duration per week was significantly higher among participants aged 25 to 34 ($p=0.05$) and 45 to 54 ($p<0.01$) years compared to the oldest group (55–66 years), and among the males compared to the females ($p=0.04$). Data transfer was mostly carried out via Wi-Fi (87.9%) rather than 2G/3G networks.

Self-reported (after 6 months) and recorded number and duration of calls were moderately correlated with Spearman correlation coefficients (r) of 0.53 and 0.57, respectively. On average, participants underestimated the number of calls they made and received (GMR of self-report to recorded=0.65, 95% CI 0.53 to 0.80; table 2). When excluding outgoing calls of 0 to 10 s (potentially 'unsuccessful' calls, n=589), the ratio somewhat increased to 0.71 (95% CI 0.59 to 0.87). The duration of calls was on average slightly overestimated by the participants with a ratio of 1.11, however, with a broad CI (95% CI 0.86 to 1.42). At baseline (0 months), participants provided slightly lower estimates of the current number and duration of calls compared to their recall at 6 months. The ratios of self-reported to recorded number and duration of calls showed a significantly increasing trend with increasing level of reported phone use, that is, underestimation at the lower levels, and overestimation at the higher levels of use (figure 1 and table 2). The ratio did not differ significantly by the covariates age, gender, educational level and type of phone user (study vs own phone). Self-reported and recorded number of text messages sent were moderately correlated ($r=0.60$), as well as self-reported data use in minutes/week and recorded data transfer in MB/week ($r=0.42$). Ten participants (10.4%) reported not having used the Internet, while actual data transfer (mean: 57.2 MB/week, range: 0.3–210.0) was recorded by the app (see online supplementary figure S2).

On average, participants held the phone for 86% of the total call time near the head. Participants who reported using the phone generally on the right side of their head did use it on average for 70.7% of the total call time on the right side versus 16.3% on the left side (table 3). Self-reported left-side users held the phone more on the left (66.2%) than the right (18.8%) side of their head. The few participants who reported using the phone on both sides of the head actually used it more on the right (52.2%) than the left (32.2%) side. For an averaged 14% of the total call time, the phone was not held near the head, because of hands-free device usage (headset: 2.9%, speaker mode: 5%, Bluetooth: 2.7%), or because of other actions that required holding the phone away from the head (3.4%). Three (5.4%), 19 (33.9%) and 11 (19.6%) participants reported having used a headset, the speaker mode of the phone or a Bluetooth headset/car kit, respectively (table 4). The percentage of recorded hands-free device usage increased with the increasing reported frequency of using hands-free devices, although numbers were small especially in the highest frequency categories.

DISCUSSION

This study used a newly developed software app to record actual mobile phone use. Not only did this provide us with information on how people use their smartphone nowadays, but also the recorded information could be used to validate self-reported mobile phone use. We observed that participants on average underestimated the number of calls they made and received by a ratio of 0.65 (self-report to recorded), while they overestimated the duration of calls by a ratio of 1.11. The

Table 1 Recorded mobile phone use, by age and gender

		Age (years)				Gender	
	Total	25–34	35–44	45–54	55–66	Male	Female
N	96	40	17	21	18	38	58
Number of calls; mean p/wk (SD)	16.1 (14.4)	16.4 (10.6)	14.0 (12.1)	22.0 (21.7)*	10.8 (11.6)	19.0 (17.2)*	14.2 (12.0)
Call duration; mean min p/wk (SD)	47.5 (56.1)	51.8 (39.7)*	43.1 (47.6)	64.0 (92.5)*	23.2 (27.0)	56.0 (64.8)*	42.0 (49.3)
Number of text messages; mean p/wk (SD)	12.4 (10.2)	13.8 (8.6)	10.1 (9.5)	13.1 (9.1)	10.5 (14.8)	11.2 (7.8)	13.1 (11.5)
Data use; mean MB p/wk (SD)	435.6 (902.1)	538.6 (1143.4)	365.1 (382.1)	463.9 (1028.5)	228.5 (218.3)	508.5 (816.4)	389.0 (956.7)

*p<0.05 (reference groups: Female, 55–66 years).

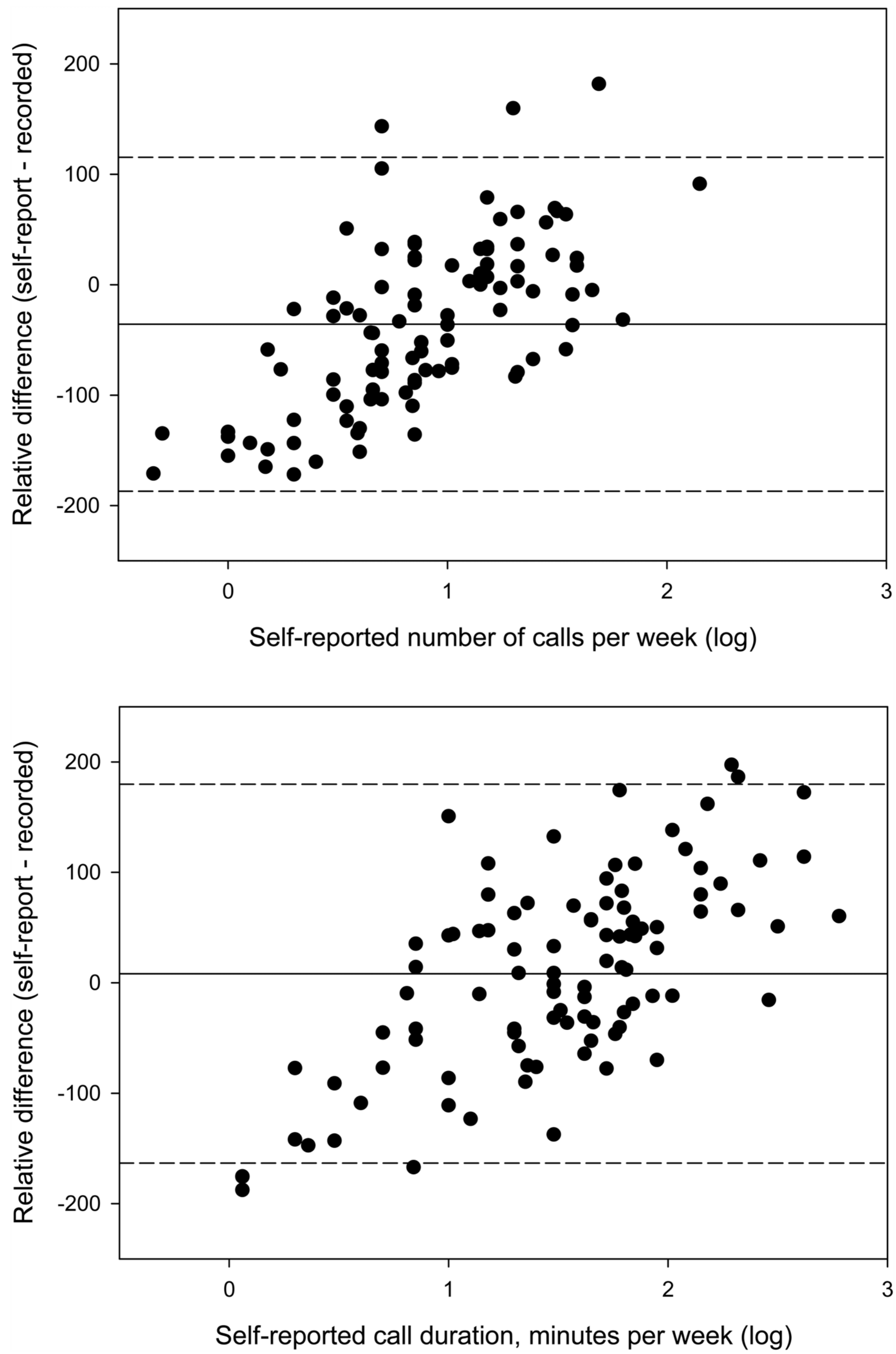
direction of underestimation/overestimation is consistent with most previous validation studies among adults; however, these studies reported higher ratios for both the number (ranging from 0.77 to 0.91) and duration (ranging from 1.39 to 1.45) of calls.[7–9] The study by Parslow *et al*[6] found an overestimation for both the number (1.7) and duration (2.8) of calls. An explanation for the lower ratios we observed could be the completeness of the data recorded by the app, compared to the often incomplete records from operators used in previous studies (billing records, eg, only contain outgoing calls).[2 8] Another explanation could be the inclusion of unsuccessful outgoing calls recorded by the app, which were most likely not included in the operator records. We made an attempt to correct for the unsuccessful calls by excluding outgoing calls of 10 s and less, which resulted in a 9% increase in the ratio for number of calls.

An important finding was the significant impact of the level of phone use on the recall, that is, participants with a higher level of reported phone use were more likely to overestimate their number and duration of calls, while underestimation was more likely among participants who reported lower levels of use. The same trend was observed in the INTERPHONE study.[8 9] This has important implications for epidemiological

Table 2 Ratio of self-report (after 6 months) to recorded number and duration of calls; by age, gender, education, type of phone user and level of use

		Number of calls		Duration of calls	
	N	Ratio*	95% CI	Ratio*	95% CI
Self-report (after 6 months) vs recorded	96	0.65	0.53 to 0.80	1.11	0.86 to 1.42
Excluding ‘potentially unsuccessful calls’ *(outgoing, ≤10 s)*	96	0.71	0.59 to 0.87	1.11	0.86 to 1.43
Self-report (0 months)† vs recorded	96	0.58	0.48 to 0.72	0.90	0.71 to 1.15
By age (years)					
25–34	40	0.58	0.49 to 0.75	1.17	0.88 to 1.57
35–44	17	0.54	0.36 to 0.82	0.69	0.56 to 1.66
45–54	21	0.77	0.44 to 1.35	1.45	0.67 to 3.14
55–66	18	0.82	0.46 to 1.48	0.80	0.40 to 1.63
		p‡=0.12		p‡=0.61	
By gender					
Male	38	0.74	0.58 to 0.94	0.93	0.69 to 1.26
Female	58	0.60	0.45 to 0.80	1.24	0.86 to 1.79
		p‡=0.32		p‡=0.11	
By educational level					
Secondary vocational education or lower	21	0.75	0.43 to 0.77	1.20	0.52 to 2.77
Higher professional or university education	63	0.65	0.51 to 0.82	1.12	0.88 to 1.43
Postgraduate education	12	0.53	0.30 to 0.95	0.90	0.39 to 2.09
		p‡=0.66		p‡=0.85	
By type of phone user					
Study phone	18	0.83	0.59 to 1.19	1.32	0.72 to 2.39
Own phone	78	0.62	0.49 to 0.78	1.06	0.80 to 1.41
		p‡=0.28		p‡=0.24	
By level of reported phone use§					
1st tertile	32	0.29	0.22 to 0.39	0.55	0.35 to 0.85
2nd tertile	31	0.69	0.53 to 0.90	0.93	0.72 to 1.20
3rd tertile	33	1.35	1.03 to 1.76	2.58	1.71 to 3.89
		p‡<0.01		p‡<0.01	

*Geometric mean of ratio self-report to recorded.
†Self-report of current mobile phone use at baseline (0 months) before using the app.
‡Adjusted for age, gender, education, type of phone user and level of phone use.
§Median number of calls per level: 1st: 3 calls/week; 2nd: 7; 3rd: 21. Median duration of calls per level: 1st: 7 min/week; 2nd: 37.5; 3rd: 105.



Figures 1 Bland-Altman plots for number and duration of calls: relative difference between self-reported and recorded information against the reported information (log transformed); lines indicate the mean and 95% limits of agreement.

studies on mobile phone use, as it will most likely lead to an underestimation of the risk, if any, for adverse health outcomes. RF dose models based on the recalled number and duration of calls should therefore account for differential recall errors by level of phone use.

Theoretically, one would expect recall to be better with shorter time intervals between the interview and the actual event. Yet in this study, we observed that the report of the current number and duration of calls at baseline (0 months) was not better than the recall after 6 months, although the baseline report and recall were covering different but consecutive time periods. This implies that people find it difficult to make an estimation of their mobile phone use, independent of time interval (at least within a 6-month time period). Interestingly, both for the number and duration of calls, participants gave slightly higher estimates at 6 months compared to baseline. This pattern was also observed in the INTERPHONE study, although more among cases than controls, where the ratio of reported to recorded mobile phone use increased with increasing time before the interview.[8] Hypothetically, this could be a form of forward telescoping,[14] that is, participants' estimates were based on more recent mobile phone use (which, following general trends in mobile phone usage, might be slightly higher) than the actual use 6 months previously.

The correlation between the self-reported and recorded number of text messages sent was moderate, but as this has little or no impact on the amount of RF dose from mobile phone use due to the very short durations, we did not explore it in further detail. This is, however, different for data use. Although the location of RF exposure from data transfer (frontal lobe of

Table 3 Laterality: self-report (after 6 months) to recorded

		Recorded (mean % (SD) of total call time)		
Self-report	N (%)*	Right side	Left side	Away from the head†
Mainly right side	30 (53.6)	70.7 (25.5)	16.3 (23.1)	13.0 (17.5)
Mainly left side	23 (41.1)	18.8 (16.7)	66.2 (20.4)	15.1 (14.6)
Both sides	3 (5.4)	52.2 (34.2)	32.2 (30.4)	15.6 (12.7)

*Only phone models included that accurately performed in the laterality tests.
†The mobile phone was not near the head during a voice call, for example, hands-free device usage, answering/ending a call.

the brain and/or other parts of the body) and the distance to the body is different from voice calls, the enormous increase in data transfer due to the arrival of smartphones makes it an important source to consider in defining RF dose from mobile phones. The amount of RF dose from data transfer depends on several factors, such as the amount of MB transferred, the upload and download speed of the Internet connection, and the exact distance to the body. These factors are, however, difficult if not impossible to report by people. We therefore asked the participants to report the amount of time spent using the Internet, which appeared to be moderately correlated with the amount of MB transferred as recorded by the app. Interestingly, we noticed that about 10% of the participants (mostly non-Android users) reported no data use, while the app did record a small amount (mean: 57.2 MB/week, vs 454.9 MB/week for the whole sample) of data transfer. This suggests that people are often unaware of the data transfer on their mobile phone, possibly by applications that run in the background (push messages).

Laterality is an important variable used in studies on mobile phone use and brain tumour risk, as a potential risk is expected to exist primarily at the side of the head where the phone is usually held. This is one of the first studies that was able to assess the position in which the phone is held during voice calls, and to compare this with self-reported laterality. A previous study by Inyang *et al*[10] using hardware-modified phones among adolescents concluded that self-reported laterality was of limited value (κ=0.3), though it is not clear how they defined HMP-measured laterality. We made several important observations regarding laterality, which will have implications for modelling RF dose within the brain. First, the mobile phone was not close to the head for the full call duration; for an average of 3.4% of the total call time (excluding hands-free device usage), the phone was away from the head, for example, to answer or end a voice call. Second, participants rarely used the mobile phone solely on one side of their head, although they did use it on average more on the side of the head they reported as the dominant side: when excluding the percentage of total call time the phone was not near the head, 81.3% at the right side for self-reported right-side users, and 77.9% at the left side for left-side users. To compare, Cardis *et al*[15] assigned 90% of exposure to the reported predominant side of the head in the INTERPHONE study, which might have led to a negatively biased estimate of contralateral exposure.[11]

The measurement of actual hands-free device usage by the software app also provided new information. Comparing the actual information with self-reported information revealed a good agreement, that is, we observed an increasing amount of recorded hands-free device usage with increasing frequency of use reported. The derived percentages could be used in exposure algorithms as average percentages of actual hands-free device usage, though the number of hands-free users in this study was small.

The smartphone app that has been used in this study as 'the golden standard' to validate self-reported mobile phone use has several advantages compared to previous validation studies using operator traffic data, SMPs or HMPs as the golden standard. First, the smartphone app was able to record additional mobile phone use information above the usual variables (ie, number and duration of phone calls), including laterality, hands-free device usage and data use. Second, the smartphone app was installed on a regular modern smartphone. This made changes in phone use behaviour due to inconvenience about the phone model less likely.[10] Still, the 'non-Android users' in our study, who used a smartphone provided by the study team, reported some changes in phone use behaviour, mainly an increase in data use. This can be explained by the fact that most non-Android users (72.2%) did not use a smartphone previously. It did, however, not seem to affect their recall, as we did not observe a significant different ratio of self-report to recorded number and duration of calls between study phone and own phone users, and no differences in recall of laterality and hands-free device usage (results not shown). Participants who used their own phone were not expected to change their mobile phone use, although there is a small risk that they modified behaviour in response to their awareness of being observed, known as 'the Hawthorne effect'.[16] We did, however, not observe a significant different use in the first week after installing the app (in which you would expect a possible effect to be strongest) and the weeks thereafter. In spite of the advantages of the smartphone app, the app and the SMPs and HMPs used in previous studies were only applied to healthy volunteers. Our study sample was skewed towards the younger ages (<35 years), females and higher educated people, though the ratio of self-report to recorded mobile phone use seemed to be not affected by those sociodemographic characteristics. Whether there is differential recall between patients and controls can be better explored by using operator records reflecting the period of use before diagnosis.

In conclusion, we used a smartphone app to record actual phone use, which had several advantages over previously used operator records, SMPs or HMPs for the validation of self-reported mobile phone use. Besides the recall error observed for the number and duration of calls, this was the first study that was able to explore the actual percentage of total call time that

Table 4 Hands-free device usage: self-report (after 6 months) to recorded

	Recorded (% of total call time)	
Self-report	N (%)*	Mean % (SD)
Headset (wired)		
No	53 (94.6)	0.2 (1.0)
Yes, low frequency	2 (3.6)	38.5 (11.3)
Yes, high frequency	1 (1.8)	77.0 (–)
Speaker mode		
No	37 (66.1)	3.7 (7.0)
Yes, low frequency	17 (30.4)	7.1 (9.1)
Yes, high frequency	2 (3.6)	10.6 (12.9)
Bluetooth (headset, car kit)		
No	45 (80.4)	0.6 (3.7)
Yes, low frequency	8 (14.3)	4.8 (13.0)
Yes, high frequency	3 (5.4)	28.4 (25.9)

*Only phone models included that accurately performed in the laterality tests.

participants held their mobile phone close to the head, and the actual percentage of hands-free device usage. Our findings have implications for epidemiological studies exploring the possible health effects of RF emissions from mobile phones, in which the exposure assessment is based on people's recall.

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