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Estimation of TETRA radio use in the Airwave Health Monitoring Study of the British police forces

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HIGHLIGHTS

- The first large observational study to make use of operator-derived records alongside self-reported information to estimate radio use as a proxy for RF-EMF exposure
- Imputed average TETRA radio usage correlates better with objective data than self-reported use
- Higher personal radio usage seen in younger and male participants as well as in police officers compared with staff
- An estimate of monthly average personal radio usage obtained for the entire cohort will allow us to carry out analyses of TETRA usage for the entire cohort in future work

ABSTRACT

Background: The Airwave Health Monitoring Study aims to investigate the possible long-term health effects of Terrestrial Trunked Radio (TETRA) use among the police forces in Great Britain. Here, we investigate whether objective data from the network operator could be used to correct for misreporting in self-reported data and expand the radio usage availability in our cohort.

Methods: We estimated average monthly usage of personal radio in the 12 months prior to enrolment from a missing value imputation model and evaluated its performance against objective and self-reported data. Factors associated with TETRA radio usage variables were investigated using Chi-square tests and analysis of variance.

Results: The imputed data were better correlated with objective than self-reported usage (Spearman correlation coefficient = 0.72 vs. 0. 52 and kappa 0.56 [95% confidence interval 0.55, 0.56] vs. 0.46 [0.45, 0.47]), although the imputation model tended to under-estimate use for higher users. Participants with higher personal radio usage were more likely to be younger, men *vs*. women and officer *vs*. staff. The median average monthly usage level for the entire cohort was estimated to be 29.3 minutes (95% CI: [7.2, 66.6]).

Conclusion: The availability of objective personal radio records for a large proportion of users allowed us to develop a robust imputation model and hence obtain personal radio usage estimates for ~50,000 participants. This substantially reduced exposure misclassification compared to using self-reported data and will allow us to carry out analyses of TETRA usage for the entire cohort in future work.

Keywords: TETRA, radiofrequency electromagnetic fields, occupational cohort, occupational exposure

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ETHICS

The study has ethical approval through the National Health Service multi-site research ethics committee (MREC/13/NW/0588). Each participant provided informed written consent to participate in the study following procedures approved by the MREC.

INTRODUCTION

The possibility of adverse health effects associated with exposure to radiofrequency (RF) electromagnetic fields (EMF) from mobile telephones or other wireless devices is an issue of public concern and scientific debate with the widespread dissemination of these technologies since the 1990s. In 2011, the International Agency for Research on Cancer (IARC) classified RF-EMF as a possible carcinogen (Group 2B) requiring additional research into the long-term effect of heavy use of mobile phones (International Agency for Research on Cancer, 2011). In particular, the evidence was considered inadequate to draw conclusions for occupational exposures to RF-EMF which are likely to be higher than those from the general public.

Terrestrial Trunked Radio (TETRA) is a digital communication system progressively adopted by Police Forces and other emergency services in Great Britain since 2001. Specific energy Absorption Rate (SAR) in the head for a typical TETRA handset varies from 1.3 to 4.0 Wkg^{-1} suggesting that exposure could exceed general population guidelines in some circumstances (although always below occupational guidelines) (Dimbylow et al., 2003). TETRA differs from GSM (Global System for Mobile Communication) mobile phone technology in terms of the average output power and transmission frequency. TETRA portable radios can, in some circumstances, exceed those from GSM900 and GSM1800 mobile phones and TETRA transmission is pulsed at 17.6 Hz (1/56.7 ms) whereas mobile phones transmission is pulsed at 217 Hz (1/4.6 ms). So the mechanism of any potential effects of RF-EMF on health may differ between TETRA and GSM based signals. In 2000, the UK Independent Expert Group on Mobile Phones (Stewart Report) suggested that TETRA-like signal modulation should be avoided in future signal coding development (Independent Expert Group on Mobile Phones, 2000) based on experimental findings suggestive of increased calcium efflux from brain tissue (Bawin et al., 1975). To address these concerns, in 2004 the UK Home Office commissioned the Airwave Health

Monitoring Study, an epidemiological cohort study into the possible long-term health effects of TETRA use among the police forces in Great Britain (Elliott et al., 2014).

To date, most epidemiological studies investigating the association between RF-EMF emitting devices and health outcomes relied on self-reported use (Lonn et al., 2004; Thomee et al., 2011; Zheng et al., 2015), with few exceptions (Auvinen et al., 2002; Aydin et al., 2011; Dreyer et al., 1999; Frei et al., 2012; Mohler et al., 2012; Schoeni et al., 2015; Schuz et al., 2006). Concerning mobile phones, self-reported use tends to overestimate true usage among low users and underestimate use among heavy users (Vrijheid et al., 2006a). In addition, random errors in exposure estimates may substantially bias risk estimates (Vrijheid et al., 2006b). Therefore, where possible, studies investigating RF-EMF should use objective instead of self-reported usage data.

One of the main strengths of the Airwave Health Monitoring Study is the availability of objective personal radio records from the network operator (Airwave O_2) for a large proportion of enrolled police forces officers and staff. We previously showed that around 60% of personal radio users at baseline could be linked to their operator-derived records (Vergnaud et al., 2016). Objective data on personal radio use were available both prior and subsequent to entry into the study for up to 10 years in total. Compared with objective data, participants under-reported the number, and over-reported the duration of calls by a factor of around 4 and 1.6 respectively (Vergnaud et al., 2016).

In the present study, we used available data from objective records and self-reports to derive an imputation model to obtain improved estimates of the use of TETRA radio for the entire cohort of ~50,000 people. In this way we provide the basis for epidemiological investigation of potential health effects associated with TETRA use, taking advantage of data on the entire cohort.

MATERIALS AND METHODS

Study population

The Airwave Health Monitoring Study is an occupational cohort launched in June 2004 enrolling police officers and staff across Great Britain, irrespective of their TETRA radio usage. The study design and rationale have previously been described in detail (Elliott et al., 2014). Briefly, officers and staff from each force who agreed to participate completed an enrolment questionnaire, or underwent a comprehensive health screening performed locally, or both. At the health screening, the participant filled out an extensive questionnaire on a touchscreen computer. Both questionnaires include demographic, health and lifestyle questions, and information on TETRA radio usage. The time between the enrolment questionnaire and the health screening was determined by logistical constraints and varied between 6 months and one or more years. By 31 March 2015, at the end of recruitment, the Airwave Health Monitoring Study had enrolled 53,119 participants. Response rate averaged around 50% of employees (Elliott et al., 2014). Participants signed a consent form permitting use of their data and samples for future research. The study has ethical approval through the National Health Service multi-site research ethics committee (MREC/13/NW/0588). In the present study, of the 51,904 participants with self-reported information on personal radio usage available, we excluded those who reported that they only used pool radios (portable radios available to use on demand by any police officer or staff, N=1,586). This is because individual operator-derived records were not available for those radios and self-reported usage was less precisely assessed compared to other radio types. This led to a sample of 50,318 participants for the present study (95 % of the whole sample, Supplementary Figure 1).

Statistical methods

a. Estimation of personal radio usage

We received the operator data for all the participating forces (except for special forces) from Home Office and the data included both incoming and outgoing calls in seconds. As the data were all obtained from a single operator, there were no differences between forces in the range or resolution of data available (this may not be the case in studies that access records from more than one operator). Definition of usage in the present study is restricted to the time that participants were exposed to RF-EMF, i.e. only when the user pressed the radio button to speak, not when he or she was in listening mode, which has no RF-EMF emission. Details of the linkage process between each personal radio user and his or her operator-derived personal radio records have been described previously (Vergnaud et al., 2016).

We defined our exposure measure as average monthly call duration (personal radio) during the year preceding enrolment to the study. In previous work (Vergnaud et al., 2016) we have shown that this measure was a better estimate of usual radio use than usage in the last shift, which provided only limited information on the amount and duration of use, and, as it was based on self-report from questionnaire, might be affected by misreporting or responder bias. Among the 33,788 participants who were personal radio users based on the self-reported data on number and duration of outgoing calls in the last shift, objective information on radio use was available from the network operator for 21,449 (63.5%, Supplementary Figure 1). Of those, 976 (4.6%) reported not using a personal radio in the questionnaire but had operator-derived records found in the year preceding. Upon inspection, the majority of those participants either stopped using their radio during the year preceding enrolment into the study or were very infrequent users; they were therefore included in the user group.

We used objective data on personal radio usage where these were available. Where we did not find an objective record on use, we assigned the personal radio usage of reported non-users at enrolment to zero (N=16,530). For those who reported personal radio use at enrolment but where objective data were missing (N= 12,339, 36.5% of personal radio users), we used multiple missing value imputation to estimate usage from self-reported data and participant's characteristics at enrolment. For validation purposes, we also obtained an imputation value for individuals with objective data, in order to compare these values.

We assumed that missing objective personal radio usage data were missing at random. To avoid making assumptions about the associations between the explanatory variables and personal radio usage, we tested the performance of different machine learning algorithms (Jordan and Mitchell, 2015) as well as traditional linear and Bayesian models. Here we present results for the Gradient Boosting Regressor machine learning method (results for other methods are shown in Supplementary Table 4). Personal radio use was the only variable for which missing values were imputed. Amount of radio use was log transformed because of positive skew. Modelling was performed using the Scikit-learn package of Python v2.7 (Pedregosa et al., 2011). All explanatory variables were first categorised and we then used principal components analysis (PCA) to obtain the top principal components explaining the most variance from the original set of explanatory variables. More details about the imputation procedures can be found in Supplementary Methods, Supplementary Figure 2A and 2B.

Information on socio-demographic characteristics, lifestyle and medical history were extracted either from the questionnaire completed at the time of the health screening (75.7% of participants) or from the paper questionnaire received at the time of enrolment (24.3% of participants). Measures such as body mass index and blood pressure were available only for those who attended the health screening. The explanatory variables included in the model are listed in Supplementary Table 1.

b. Imputation performance and re-classification of personal radio usage

We compared agreement between imputed and objective estimates vs. agreement between self-reported and objective estimates using Spearman correlation coefficients and kappa statistics, to evaluate if using imputation reduced error due to mis-reporting. (Note that average monthly call duration could not be calculated from self-reported data, as information on the number and duration of calls was obtained for the last shift only.) Since both imputed and objective personal radio usage variables estimate the same quantity (i.e. average monthly call duration in the year preceding enrolment), a Bland Altman plot (Bland and Altman, 1999) was created to evaluate presence of systematic error and whether this was dependent on the amount of use. A spline regression was fitted with 4 knots placed at the 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles.

We created a categorical variable that combined information on self-reported intensity and frequency of personal radio usage (Supplementary Methods). Participants who reported using personal radio were further categorized into low, medium and high usage groups, by tertiles of their usage intensity; the remainder of the participants were classified either as non-users or usage status was unknown (Supplementary Table 2).

RESULTS

Factors associated with personal radio usage at baseline

Usage of personal radio was higher in men compared to women and officers compared to staff (Table 1) and usage decreased with age. High users (in the third tertile of usage combined across objective records and imputation data) were more likely to use hands free kit compared to low users (in the first tertile). Characteristics of users according to objective usage data are presented in Supplementary Table 3.

Multiple missing value imputation

Using the Gradient Boosting Regressor machine learning method (Supplementary Table 4), explanatory variables contributing to the model were the top two principal components of the PCA, self-reported frequency of usage of personal radio, job title, self-reported number and duration of personal radio calls during the last shift, age, number of years of service in the current role, force, month that the questionnaire was completed, number of years since starting using TETRA radio and physical activity (Supplementary Figures 3A and 3B).

Improved classification in personal radio usage at baseline

Monthly personal radio call duration estimates in the year preceding enrolment are shown in Table 2. Median imputed average monthly usage for users without objective data was 15.7 minutes, as compared with 41.8 minutes for participants with objective data. While the imputed usage estimates and objective measures were similar for users in the two lower tertiles, the difference between the two measures was larger in the highest tertile (Table 2 and Figure 1), suggesting that the imputation tended to underestimate use for higher users. The median difference between objective and imputed values was 3 minutes (95th percentile of the difference 61 minutes, Figure 1). Overall, the median monthly average personal radio usage at enrolment for users in the entire cohort was 29.3 minutes (95% confidence interval [CI]: 7.2, 66.6, Table 2).

The Spearman correlation coefficients between objective and self-reported personal radio usage ranged from 0.40 to 0.52. The correlation increased to 0.72 when comparing objective to imputed personal radio usage (Table 3). Looking at categorical variables, kappa statistics increased from 0.46 (95% CI: 0.45, 0.47) to 0.56 (0.55, 0.56) when using imputed instead of self-reported data (Table 4) and when non-users were excluded from the calculation the kappa values were 0.28 (0.27, 0.29) and 0.42 (0.41, 0.43), respectively.

We also examined the correlation between objective and imputed data by force. For the 24 forces with more than 5% of objective data among personal radio users, the Spearman correlation coefficients ranged from 0.29 to 0.79 and were 0.40 or more in all but two forces (Supplementary Table 5, Supplementary Figure 4).

DISCUSSION

In the present study, we used objective TETRA radio usage in a sub-sample of our cohort population to impute monthly average personal radio usage for users who only had self-reported data for the last shift. We thus obtained an estimate of baseline personal radio usage for all ~50,000 participants in the cohort, and for a longer period of observation than available from the limited self-reported data on radio usage alone. Moreover, the imputed results were better correlated with objective measures than those from self-reports.

To our knowledge, only one small study on RF-EMF corrected for misreporting in self-reported usage from operator-derived records. Among 108 New Zealand adolescents, the objective amount of SMS-texting was retrieved from the phone operator and estimated according to self-reported information using a Bayesian model (Redmayne et al., 2013). In agreement with our findings, the authors concluded that estimated usage was substantially less biased than self-reported usage. While previous studies on mobile phone use have compared operator data for a subset of participants with self-reported data to estimate bias in self-reported data (Aydin et al., 2011; Frei et al., 2012; Mohler et al., 2012; Schoeni et al., 2015), only one other study has combined information from both sources of data to correct self-reported usage estimates, although not on the scale of our cohort (Roser et al., 2015;

Schoeni et al., 2017) . Thus in the HERMES study of Swiss adolescents, operator provided data were used in addition to questionnaire data to derive RF-EMF dose measures with no association found for these measures in relation to health symptoms (Schoeni et al., 2017). Our results are relevant to other studies with objective data on use of RF-EMF devices. In the COSMOS Study, a cohort of more than 300,000 participants that aims to investigate the potential effects of mobile phone use on long-term health (Schuz et al., 2011), objective data on phone use from the mobile phone operators has been obtained and could be used to improve estimation of use for epidemiological analyses.

In the present study, the highest users (top 5%) of personal radio at baseline transmitted on their radios for an average of 3 hours 9 minutes per month (from objective data). This is lower than the average time exposed to RF-EMF for the heavy users of mobile phones previously reported (Heinavaara et al., 2011; Vrijheid et al., 2006a). In this regard, it is of note that personal radio usage in the present study does not include listening time, as no RF-EMF is emitted by the radio in listening mode. In addition, the characteristics of TETRA differ from GSM, so the effects of exposure for the same amount of time may not be directly comparable.

Our study has a number of limitations. First, we included radio use as a proxy for RF-EMF exposure as direct estimates of RF-EMF exposure, such as SAR, could not be estimated with any certainty. SAR values vary depending on a variety of circumstances, including position of the device, distance from the body and type of radio. The SAR values from a representative TETRA handset in a model of the head varied from 1.3 to 4.0 Wkg^{-1} depending on the type of antenna and the handset position (Dimbylow et al., 2003). A German study investigating TETRA dosimetry for two handsets (Motorola MTP 850 and Sepura STP 8000) worn on the chest or the belt found that SAR values ranged from 0.9 to 2.3 Wkg^{-1} depending on gender and belt vs. breast pocket position (Bodendorf, 2012). SAR values were similar for both radio sets but could vary according to the angle with the body when worn on the belt, and could be higher for a handset terminal used inside a vehicle. However, these models of radio were not commonly used in the UK police forces. Moreover, as also reported in a previous study of the Lancashire police force (van Tongeren, 2005), the majority of the transmissions in the present study were carried out using hands-free kit, i.e. distant from the head.

Secondly, self-reported information on usage for most participants was based only on questionnaire data for the last shift, which could vary by duration and timing of the shift, and thus gave only a limited picture of radio use (although participants recruited from July 2009 were also asked to provide a 7-day record of radio usage giving a more complete picture for those participants). These limited data reduced the performance of the imputation model especially with higher use (although this affected relatively few individuals). The opportunity to obtain very detailed information by questionnaire was limited by feasibility and participant burden, as well as potential for incomplete and inaccurate reporting. By comparison, the operator data were available for a much longer period and were obtained directly, but such data may not always be available. A further limitation is the fact that the complete picture of radio use prior to enrolment was known for only 41% of participants with objective data, although the period with missing data was often small compared to the duration of data available.

Despite these limitations, the imputation still substantially reduced error and misclassification compared to self-reported data and presents an advance compared to previous studies that relied solely on self-reports. This is the first large observational study to make use of operator-derived records alongside self-reported information to estimate radio use as a proxy for RF-EMF exposure. The availability of personal radio usage estimates for ~50,000 police officers and staff, to our knowledge the largest collection of such data in the world, will allow us to carry out analyses of TETRA usage for the entire cohort in future work.

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COMPETING INTERESTS

There are no competing interests to declare.

AUTHORS' CONTRIBUTIONS

Anne-Claire Vergnaud designed the present study, she led the development of the algorithm for assigning TETRA use to individual participants, supervised the implementation and statistical analyses of the study and wrote the first draft of the paper. Paul Elliott is the principal investigator of the Airwave Health Monitoring Study. He co-designed the study, co-wrote the paper, and has primary responsibility for final content. Maria Aresu performed the statistical analyses and Dennis McRobie was responsible for acquiring and analysing operator derived records data. Håvard Wahl Kongsgård designed and implemented the imputation model. Deepa Singh was responsible for setting up the enrolment in each police force. Jeanette Spear and Andy Heard developed and maintained the database. He Gao contributed to the data analysis and writing of the paper. James R Carpenter advised on the multiple imputation model and other statistical aspects of the study. All authors approved the final version of the manuscript.

Table 1. Participant characteristics according to estimated personal radio usage at baseline (N=50,318)

	Non-user	Tertile 1 Median= 3.40 Range(0.00-12.85)	Tertile 2 Median= 29.25 Range(12.86-51.56)	Tertile 3 Median=86.31 Range(51.57-671.35)	P
Total (%)	16530 (32.8)	11262 (22.4)	11263 (22.4)	11263 (22.4)	
Gender (%)					<0.0001
Women	9306 (50.5)	3508 (19.0)	3108 (16.9)	2520 (13.7)	
Men	7224 (22.7)	7754 (24.3)	8155 (25.6)	8743 (27.4)	
Rank (%)					<0.0001
Officer	5173 (16.0)	8724 (26.9)	8527 (26.3)	9949 (30.7)	
Staff	9176 (75.4)	1058 (8.7)	1318 (10.8)	610 (5.0)	
Missing	2181 (37.7)	1480 (25.6)	1418 (24.5)	704 (12.2)	
Education (%)					
Left school before taking GCSEs	624 (43.6)	328 (22.9)	260 (18.2)	220 (15.4)	<0.0001
GCSE[&] or equivalent	3863 (33.2)	2703 (23.2)	2446 (21.0)	2632 (22.6)	
Vocational qualifications	856 (31.3)	558 (20.4)	612 (22.4)	712 (26.0)	
A levels or equivalent	3658 (29.8)	2793 (22.8)	26509 (21.6)	3164 (25.8)	
Bachelor degree or equivalent	2637 (32.1)	1855 (22.6)	1771 (21.5)	1962 (23.9)	
Postgraduate qualifications	1247 (50.9)	587 (23.9)	325 (13.3)	293 (11.9)	
Missing	3645 (31.5)	24408 (21.1)	3200 (27.7)	2280 (19.7)	
Smoking status (%)					
Current smoker	1819 (34.6)	1089 (20.7)	1176 (22.3)	1179 (22.4)	<0.0001
Past smoker	4053 (36.8)	2565 (23.3)	2278 (20.7)	2125 (19.3)	
Non-smoker	10425 (31.5)	7373 (22.3)	75808 (22.9)	7737 (23.4)	
Missing	233 (25.3)	235 (25.5)	231 (25.1)	222 (24.1)	
Age (%)					
<30 years	1764 (24.1)	680 (9.3)	2004 (27.4)	2860 (39.1)	<0.0001
31-40 years	4135 (24.9)	3432 (20.6)	4331 (26.0)	4736 (28.5)	

41-50 years	6179 (32.5)	5632 (29.6)	4041 (21.2)	3189 (16.7)	
≥50 years	4452 (60.7)	1518 (20.7)	887 (12.1)	478 (6.5)	
Use of hand free kit (%)					<0.0001
None of the time	-	4125 (47.9)	2557 (29.7)	1928 (22.4)	
Some of the time	-	3791 (36.0)	3672 (34.8)	3075 (29.2)	
All of the time	-	1514 (14.4)	3514 (33.4)	5504 (52.3)	
Missing	-	1832 (44.6)	1520 (37.0)	756 (18.4)	
User of car mounted radio (%)					
Yes	487 (2.4)	4761 (23.1)	6614 (32.0)	8781 (42.5)	<0.0001
No	16028 (54.3)	6435 (21.8)	4607 (15.6)	2424 (8.2)	
Missing	15 (8.3)	66 (36.5)	42 (23.2)	58 (32.0)	
User of desk mounted radio (%)					
Yes	1331 (17.9)	2567 (34.5)	1860 (25.0)	16768 (22.6)	<0.0001
No	15196 (35.6)	8648 (20.2)	9354 (21.9)	9527 (22.3)	
Missing	3 (1.9)	47 (29.9)	49 (31.2)	58 (36.0)	
User of motorbike mounted radio (%)					
Yes	53 (5.8)	240 (26.3)	329 (36.1)	289 (31.7)	<0.0001
No	16462 (33.4)	10956 (22.3)	10892 (22.1)	10916 (22.2)	
Missing	15 (8.3)	66 (36.5)	42 (23.2)	58 (32.0)	
User of covert radio (%)					
Yes	338 (5.1)	2400 (36.1)	2211 (33.2)	1701 (25.6)	<0.0001
No	16186 (37.2)	8817 (20.2)	9019 (20.7)	9521 (21.9)	
Missing	6 (4.8)	45 (36.0)	33 (26.4)	41 (32.8)	

[&] GCSE, General Certificate of Secondary Education

The tertiles are based on the distribution of estimated personal radio usage in the combined data (objective and imputed) and the unit is minutes per month.

Table 2. Median (inter-quartile range) of average monthly call duration in minutes from estimated personal radio usage during the year preceding enrolment

	All	No use	Tertile 1	Tertile 2	Tertile 3
Objective	41.8 (11.0-84.6) (N=21,449)	NA	2.3 (0.5-6.3) (N=5,747)	30.9 (21.4-40.5) (N=6,366)	92.0 (70.0-125.7) (N=9,336)
Imputed	15.7 (5.1-38.1) (N=12,339)	NA	4.3 (2.0-7.8) (N=5,515)	27.2 (19.2-37.6) (N=4,897)	69.3 (58.7-84.3) (N=1,927)
Combined	29.3 (7.2-66.6) (N=33,788)	NA	3.4 (1.1-7.2) (N=11,262)	29.3 (20.3-39.3) (N=11,263)	86.3 (66.6-118.6) (N=11,263)

Tertiles are based on the distribution of estimated personal radio usage in the combined data (objective and imputed).

Table 3. Spearman correlation coefficients between self-reported, imputed and objective personal radio usage estimates among users at baseline (N=18,122)

	Imputed usual personal radio usage	Self-reported number of calls during the last shift	Self-reported total duration of calls during the last shift
Objective usual personal radio usage	0.72	0.52	0.40
Imputed usual personal radio usage	-	0.67	0.52
Self-reported number of calls during the last shift	-	-	0.70

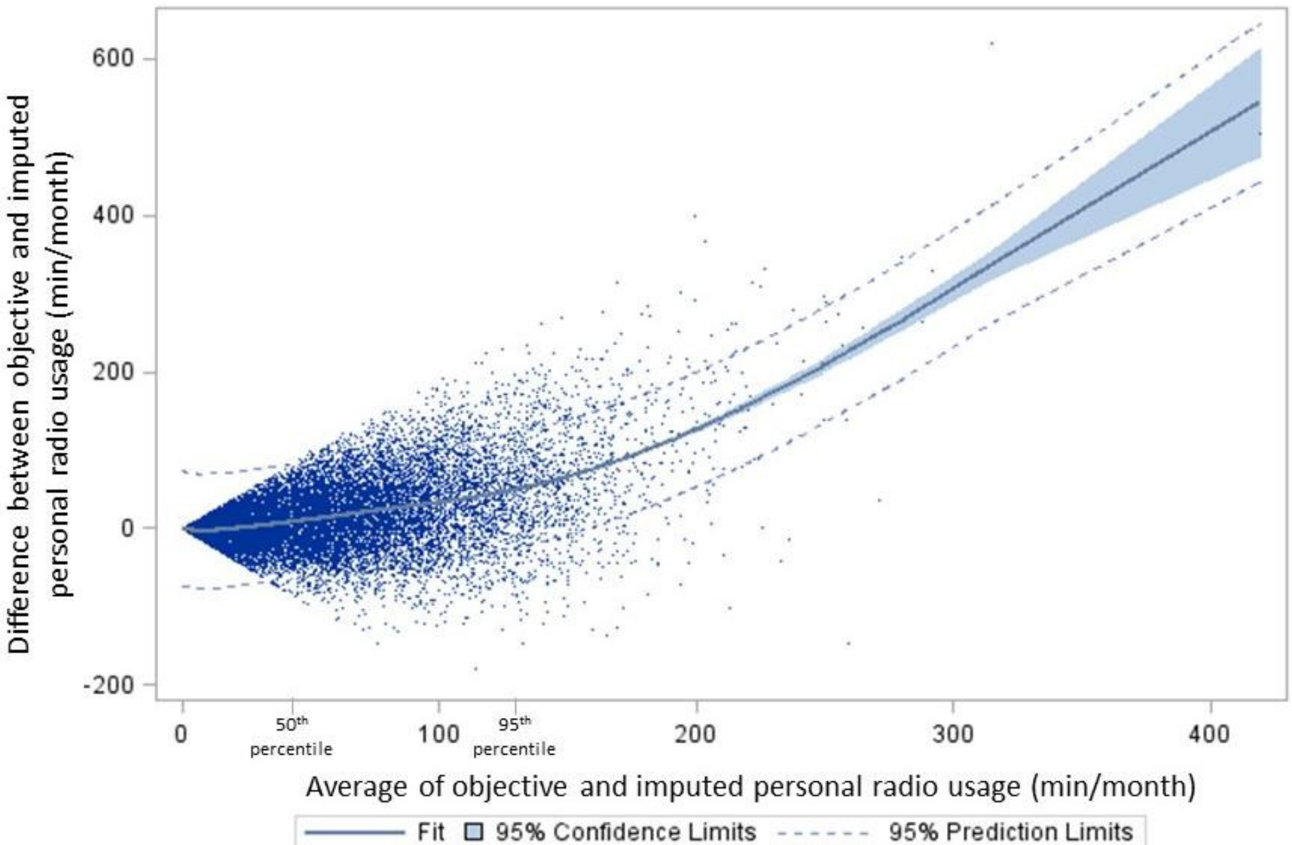
All p-values <0.0001

Table 4. Re-classification between self-reported, imputed and objective personal radio usage estimates at baseline (N= 26,746)

	Objective usual personal radio usage[1]				
	Non-user	Low usage	Medium usage	High usage	Kappa (95% CI)
Self-reported personal radio usage[2]					
Non-user, N (%)	6,180 (23.1)	756 (2.8)	139 (0.5)	66 (0.2)	
Low usage, N (%)	506 (1.9)	4,660 (17.4)	3,049 (11.4)	1,560 (5.8)	0.46 (0.45,0.47)
Medium usage, N (%)	41 (0.1)	794 (3.0)	1,904 (7.1)	1,825 (6.8)	
High usage, N (%)	41 (0.1)	449 (1.7)	1,568 (5.9)	3,208 (12.0)	
Imputed usual personal radio usage[3]					
Non-user, N (%)	6,180 (23.1)	756 (2.8)	139 (0.5)	66 (0.2)	
Low usage, N (%)	497 (1.9)	4,247 (15.9)	1,428 (5.3)	363 (1.4)	0.56 (0.55,0.56)
Medium usage, N (%)	74 (0.3)	1,434 (5.4)	3,122 (11.7)	1,905 (7.1)	
High usage, N (%)	17 (0.1)	222 (0.8)	1,971 (7.4)	4,325 (16.2)	

[1]Low, medium and high usage categories were created using tertiles of the objective average of monthly call durations over the year preceding baseline [2]Low, medium and high usage categories were created combining the tertiles of the self-reported number of calls during the last shift and the self-reported frequency of usage ("some of the time" vs. "a lot of the time"). More detail in Supplementary material [3]Low, medium and high usage categories were created using tertiles of the imputed average of monthly call durations over the year preceding baseline. All tertiles were calculated in the sub-sample of participants with all three variables available.

Figure 1. Bland-Altman plot showing difference between objective and imputed personal radio estimates according to the average of the two



Spline regression of the difference between objective and imputed personal radio usage according to the average of the two with 4 knots placed at the 5th, 25th, 75th and 95th percentiles. The 50th and 95th percentiles of the average of objective and imputed personal radio usage are displayed on the X axis to help interpretation.

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