Symptoms and the use of wireless communication devices: a prospective cohort study in Swiss adolescents

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Background
We investigated whether radiofrequency electromagnetic fields (RF-EMF) from mobile phones and other wireless devices or by the wireless device use itself due to non-radiation related factors in that context are associated with an increase in health symptom reports of adolescents in Central Switzerland.

Methods
In a prospective cohort study, 439 study participants (participation rate: 36.8%) aged 12-17 years, completed questionnaires about their mobile and cordless phone use, their self-reported symptoms and possible confounding factors at baseline (2012/2013) and one year later (2013/2014). Operator recorded mobile phone data was obtained for a subgroup of 234 adolescents. RF-EMF dose measures considering various factors affecting RF-EMF exposure were computed for the brain and the whole body.
Data were analysed using a mixed-logistic cross-sectional model and a cohort approach, where we investigated whether cumulative dose over one year was related to a new onset of a symptom between baseline and follow-up. All analyses were adjusted for relevant confounders.

Results
Participation rate in the follow-up was 97% (425 participants). In both analyses, cross-sectional and cohort, various symptoms tended to be mostly associated with usage measures that are only marginally related to RF-EMF exposure such as the duration of data traffic on the mobile phone (e.g. OR for tiredness: 2.33; 95%CI: 1.54 to 3.52 for cross-sectional analyses and OR: 2.70; 95%CI:1.52 to 4.80 for cohort analyses) and number of text messages sent per day (tiredness: OR:1.81; 95%CI:1.20 to 2.74 and OR:1.87; 95%CI:1.04 to 3.38). Outcomes were less strongly or not associated with mobile phone call duration and RF-EMF dose measures.

Conclusions
Stronger associations between symptoms of ill health and wireless communication device use than for RF-EMF dose measures were observed. Such a result pattern does not support a causal association between RF-EMF exposure and health symptoms of adolescents but rather suggests that other aspects of extensive media use are related to symptoms.

Key Words: Mobile phone, RF-EMF, symptoms, adolescents, dose

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1. INTRODUCTION

Use of wireless communication devices by adolescents has substantially increased in the last few years (Waller et al. 2016). This development has raised public concerns regarding adverse health effects especially in young people since the lifetime exposure of adolescents will be longer than that of present-day adults. It has been suggested that children and adolescents may be more susceptible to RF-EMF exposure due to their still developing nervous system (Kheifets et al. 2005).

Several studies have focused on mobile phone use and health symptoms in children and adolescents relying on self-reported number or duration of mobile phone calls and texts as an exposure proxy for RF-EMF. In a nationwide Taiwanese cross-sectional study,Chiu et al. (2014) found that mobile phone use was associated with a significantly increased odds ratio (OR) for headache and migraine (OR: 1.42, 95%CI: 1.12 to 1.81) and skin itches (OR: 1.84, 95%CI: 1.47 to 2.29). In a large Swedish cross-sectional study of 2000 adolescents, self-reported use of mobile phones was related to self-reported health complaints such as tiredness, stress, headache, anxiety, concentration difficulties and sleep disturbances (Soderqvist et al. 2008). Redmayne et al. (2013) found significant cross-sectional associations between adolescents' well-being and their wireless phone use, with most consistent associations for headache. In a cross-sectional Korean study, feeling of discomfort and dry skin were associated with the number of outgoing calls per day and dry skin, fatigue and dizziness were associated with average duration per call (Byun et al. 2013). Ikeda et al. (2014) found associations between mobile phone use and depressed mood or fatigue, respectively in 2785 Japanese high school students. In a representative Finnish sample of 7300 adolescents, high-mobile phone users showed more symptoms of depression and sleep disturbances than low-mobile phone users (Koivusilta et al. 2007). Roser et al. (2016a) found that physical well-being was significantly decreased in the 10% of adolescents belonging to the highest category in the shortened 10-item version of the Mobile Phone Problem Use Scale (Foerster et al. 2015).

Most of the existing evidence concerning the exposure of RF-EMF on adverse health effects however comes from cross-sectional studies, where changes over time cannot be assessed and where reverse causality, as well as confounding by lifestyle related factors related to mobile phone use and well-being are of concern. Another limitation in all of these studies was the self-reported mobile phone use, which has been shown to be inaccurate. Adolescents tend to substantially overestimate their amount of mobile phone use (Aydin et al. 2011; Inyang et al. 2009).

Thus, to address RF-EMF long term effects of mobile phone use, the application of a cumulative RF-EMF dose measure, which does not depend on usage only, is necessary, whereas for more transient effects recent exposure is relevant. One major factor determining RF-EMF exposure and not strongly correlated to the duration of mobile phone use is the type of network used. Calls on the UMTS network (3rd generation Universal Mobile Telecommunications System) cause on average 100-500 times less exposure than calls on the GSM network (2nd generation Global System for Mobile Communications) (Gati et al. 2009). In Switzerland both types of network are used and with the help of objectively recorded mobile phone use data provided by mobile phone operators and personal RF-EMF measurements, an integrative RF-EMF dose measure suitable for epidemiological research was calculated (Roser et al. 2015).

By applying this RF-EMF dose measure to the prospective HERMES (Health Effects Related to Mobile phonE use in adolescentS) cohort study, we thus aimed to investigate whether self-reported symptoms are associated with RF-EMF from mobile phones and other wireless devices or by the wireless device use itself due to non-radiation related factors in that context.

2. MATERIAL AND METHODS

2.1 Study procedure

For the present study, 126 schools (7th, 8th and 9th grade) from rural and urban areas in Central Switzerland were contacted by an initial phone call with the head of the school. In a subsequent visit in the classes of 24 schools that agreed to participate, 1193 adolescents were informed about the study. Participation was voluntary and had to be preceded by informed consent of the adolescents and a parent. The baseline investigation then took place in school during school time between June 2012 and February 2013. The adolescents filled in a questionnaire with questions on non-specific symptoms of ill health, use of wireless communication devices, socio demographics, and other relevant covariables. This information was complemented by a parental questionnaire with additional items such as wireless technology at home and questions on child development. Parents were asked to fill out the questionnaire and send it back directly. This procedure was repeated one year later by the same study managers with the same study participants.

A subgroup of 95 study participants participated voluntarily in personal measurements. The participants were selected so that they represent a broad range of the HERMES cohort according to basic criteria such as age, gender, school level and urbanization of home and school place. The adolescents carried a portable measurement device, a so-called exposimeter, and kept a time-activity diary application installed on a smartphone in flight-mode for about three consecutive days. This sample has been used to estimate the exposure from cordless phone base stations, WLAN access points and other people's mobile phones, which has been used for the development of the RF-EMF dose measures. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Lucerne, Switzerland on May 9th, 2012 (Ref. Nr. EK: 12025). Written informed consent was obtained from the adolescents and their parents for the participation in the study and for providing the mobile phone operator data.

2.2 Symptoms

In the written questionnaire, headache was assessed using the six-item Headache Impact Test (HIT-6) providing a summary score of all six items ranging from 36 to 78 (Kosinski et al. 2003). According to Kosinski et al. (2003), a summary score of 49 or less is considered as "headache has no impact on your life," 50 to 55 is considered as "headache has some impact on your life," 56 to 59 as "headache has substantial impact on your life" and 60 or more as "headache has a very severe impact on your life." A binary variable was created by using 56 as the cut-off value. Tiredness, lack of energy, lack of concentration and rapid exhaustibility (referred to as exhaustibility) were assessed using a four-point Likert scale with categories "never," "rare," "moderate" and "severe." Binary variables were created by combining answer categories "never" with "rare" and "moderate" with "severe". Physical well-being was assessed using the dimension "Physical Well-being" from the Kidscreen-52 questionnaire. This dimension includes five questions exploring the level of adolescents' physical activity, energy and fitness (The KIDSCREEN Group Europe, Hadjem et al. 2010; Ravens-Sieberer et al. 2005). A binary variable was created by using the mean minus half a standard deviation as the cut-off, which is suggested as the guiding principle according to the official Kidscreen questionnaire handbook. For coherent data presentation, the Kidscreen Well-being scale was inverted and is expressed as ill-being scale.

In most health questions, we referred to the time period 4 weeks prior to the date of examination.

2.3 Exposure data

In the written adolescent questionnaire, all study participants were asked about call duration with their own or any other mobile phone (referred to as duration mobile phone calls), call duration with cordless (fixed line) phone and duration of data traffic on the mobile phone, e.g. for surfing and streaming. The duration of gaming on computers and TV and number of all kind of text messages (SMS, WhatsApp etc.) are not, or only marginally relevant for RF-EMF exposure and were thus asked about to be used as negative exposure control variables in the analyses.

Informed consent to obtain objectively recorded mobile phone use data from the mobile phone operators was given by 234 out of 439 study participants and their parents. This included duration of each call and on which network (GSM or UMTS) it started, number of SMS (text messages) sent per day and volume of data traffic (MB/day). Data were obtained for up to 18 months, from 6 months before baseline until the follow-up investigation.

2.4 RF-EMF dose measures

To be able to calculate a RF-EMF dose to the brain and the whole body of the participating adolescents, an integrative RF-EMF exposure surrogate including various factors affecting near-field and far-field RF-EMF exposure was developed, which is described in detail in Roser et al. (2015). The near-field component combines the exposure from the use of wireless devices (mobile phones, cordless phones, computer/laptop/tablet connected to wireless internet (WLAN)). For mobile phone calls, we also considered the proportion in each network type (network type proportion). Among participants for whom we obtained operator data, network type proportion was calculated directly from objective information. For the other participants, the network type proportion was predicted by mixed linear regression models with mobile phone operator, duration of mobile internet use on the mobile phone, and modelled UMTS exposure levels at home as input variables, and school as a cluster variable. The far-field component aggregates the exposure from environmental sources, which were derived from propagation modelling for radio and TV broadcast transmitters as well as for mobile phone base stations (Bürgi et al. 2010; Bürgi et al. 2008). Exposure from cordless phone base stations, WLAN access points and other people’s mobile phones were estimated by linear regression models calibrated on the personal measurement data available from 95 study participants (Roser et al. 2016c).

Specific absorption rates (SAR) for the brain and the whole body were obtained from the literature (Gati et al. 2009; Huang et al. 2014; Lauer et al. 2013; Persson et al. 2012; Vrijheid et al. 2009b; SEAWIND. 2013; Hadjem et al. 2010) for all exposure relevant situations, which included mobile and cordless phone call durations, duration of use of computer/laptop/tablet connected to WLAN, duration of mobile internet use on the mobile phone, radio and TV broadcast transmitters, other people's mobile phones, WLAN access points, and cordless phone base stations. The brain and whole body dose for each study participant were calculated by summing the products of their SAR values by the average exposure duration per day for each exposure situation. This calculation was done twice: first, using exposure duration of mobile phone calls obtained from the questionnaire for the whole sample (dose for the whole sample); and second, mobile phone call durations from the mobile phone operator records for the subsample with that data (dose for the sample with operator data). Since no data was found that translates operator recorded data traffic by a mobile phone into a SAR value, we had to use self-reported duration of data traffic by mobile phone for the dose calculation in the operator sample. Similarly, DECT phone use is self-reported in both samples.

2.5 Cumulative exposure data

For the objective exposure variables (volume of data traffic, duration of mobile phone calls and number of SMS sent), data from the whole period between baseline and follow-up investigation were summed up and divided by the time between baseline and follow-up investigation, to obtain averages per day for easier interpretation. For every self-reported exposure variable (duration mobile phone calls, call duration with cordless phone, duration of data traffic on the mobile phone, duration of gaming and number of all kind of text messages) and for the dose measures (brain and whole body dose) a mean between baseline and follow-up data was calculated.

2.6 Statistical Analysis

Two main analyses (a and b) were performed to investigate possible associations between self-reported symptoms and non-radiation related factors in the context of mobile phone use or RF-EMF sources in the everyday environment:

a) A mixed-logistic cross-sectional regression analysis of a combined dataset consisting of baseline and follow-up data, accounting for the repeated measures for each individual.
b) A cohort analysis, including all participants without the target symptom at baseline (based on the binary category), to investigate, whether occurrence of the symptom was related to cumulative wireless device use or cumulative RF-EMF dose.

In both analyses (a and b) two different approaches were chosen. In a primary approach (I), exposure-response associations were investigated using a logistic regression model. All exposure variables were used continuously, using a linear term and odds ratios were expressed per interquartile change in exposure, in order to be able to compare between different exposure surrogates. In a second approach (II), a logistic regression model based on three exposure categories for all exposure variables was applied: exposure or dose below median (reference), 50^{th} to 75^{th} percentile and the top 25 per cent.

All models were adjusted for age, sex, nationality, school level (college preparatory high school or high school), physical activity, alcohol consumption and education of parents. In the cohort analyses we adjusted for confounders at follow-up. Additionally, all models of the cohort analysis (b) were adjusted for change in body height between baseline and follow-up and the time between baseline and follow-up in months.

Linear regression imputation (14 missing values at baseline and 10 missing values at follow-up for alcohol consumption; 7 missing values at baseline and 6 missing values at follow-up for information on body height) or imputation of a common category (2 missing values at baseline and 1 missing value at follow-up for frequency of physical activity; 60 missing values for educational level of the parents) was used to impute missing values in the confounder variables. Statistical analyses were carried out using STATA version 12.1 (StataCorp, College Station, USA). Figures were made with the software R using version R for Windows 3.0.1.

3. RESULTS

439 students (participation rate: 36.8%) aged 12 to 17 years from 24 schools (participation rate: 19.1%) from rural and urban areas in Central Switzerland participated in the baseline investigation of the HERMES study. 412 (93.9%) study participants owned a mobile phone at baseline. In the follow-up investigation one year later, 425 study participants (participation rate: 96.8%) took part. 416 (97.9%) study participants owned a mobile phone at follow-up. Between baseline and follow-up, objectively recorded mobile phone use data was available

for 234 study participants. The follow-up investigation was on average 12.5 months after baseline. The characteristics of the study participants are listed in Table 1.

3.1 RF-EMF dose and usage related exposure

Table 2 gives an overview of the samples and their variables.

The summary statistics of all exposure and dose measures from the dataset of the cumulative data can be found in table 3. Mean self-reported mobile phone call duration was 16.0 min/day whereas mean operator recorded mobile phone call duration was 1.9 min/day. Self-reported mobile phone call duration of those we obtained operator recorded data was 15.3 min/d. When subtracting calls that have been reported to be made on other people's mobile phones, it was still 13.3 min/d. Thus, self-reported call duration is 7 times higher than what is recorded by their operator.

Most relevant contributors for the brain dose are calls on the GSM network (on average 93.3% for the whole sample and 58.7% for the sample with operator data) followed by calls with the cordless phones (4.2% and 21.0%, respectively). For the whole body dose, calls on the GSM network (on average 66.9% for the whole sample and 19.5% for the sample with operator data), the use of computer/laptop/tablet connected to WLAN (12.0% and 29.1%, respectively) and data traffic on mobile phones (8.1% and 22.3%, respectively) counted for the most part. Less important for the dose measures were exposure from radio and TV broadcast transmitters (brain dose: 0.1% and 0.4%, respectively; whole body dose: 0.3% and 0.9%, respectively) and mobile phone base stations (brain dose: 0.6% and 3.5%, respectively; whole body dose: 2.0% and 4.8%, respectively).

A substantial correlation was found between the cumulative usage measures and the cumulative RF-EMF doses: a kappa coefficient of 0.62 was found for self-reported mobile phone call duration and brain dose of the whole sample. Also the whole body dose of the whole sample was highly correlated with self-reported mobile phone call duration (0.67). Duration of mobile phone use is shorter according to objective data and thus, the contribution of this exposure condition to the total RF-EMF dose is smaller. As a consequence correlation between objectively recorded mobile phone call duration and brain dose was lower (0.48) than for self-reported data (0.62). The same holds for the correlation between objectively recorded mobile phone call duration and whole body dose (0.28).

The correlation between whole body dose of the sample with operator data and data traffic on the mobile phone and duration gaming was 0.28 and 0.15, respectively.

3.2 Associations between symptoms and usage related exposures or RF-EMF doses

3.2.1 Mixed-logistic cross-sectional analyses (a)

Figure 1 and tableS2 shows the odds ratios (OR) related to an interquartile increase in self-reported exposure variables and the dose measures of the whole sample estimated by means of a mixed-logistic cross-sectional model of baseline and follow-up data. These analyses with continuous exposure variables showed a tendency towards increased odds ratios for all the symptoms in relation to various self-reported usage measures. Typically strongest associations were observed for duration of data traffic on the mobile phone and number of text messages sent. Associations with RF-EMF dose measures for the whole sample tended to be small but were statistically significant for headache and exhaustibility. An analysis based on three exposure categories with cut-offs at the median and the 75th percentile yielded similar results as with continuous exposure variables (data not shown). The results of the mixed-logistic cross-sectional analyses of the usage and dose measures from the sample with operator data can be seen in the supplemental tableS2. Except for a significant increased odds ratio of exhaustibility for the volume of data traffic on the mobile phone and of physical ill-being for number of SMS sent, none of the objective usage related exposure measures were significantly associated with any of the symptoms. In contrast, dose measures from the sample with operator data, especially the whole body dose, were significantly associated with various symptoms. The analysis based on three exposure categories yielded similar results as with continuous exposure variables (data not shown).

3.2.2 Cohort analyses (b)

Figure 2 and table 4 show the results of the cohort analyses based on self-reported data and dose measures for the whole sample. The results of the analyses with continuous exposure variables showed a similar pattern as for the mixed-logistic cross-sectional analyses (a) of baseline and follow-up data, with highest estimates for duration of data traffic on the mobile phone and number of text messages sent per day.

For the subsample with operator data, analyses of the cumulative, objectively recorded mobile phone measures (volume data traffic, duration of mobile phone calls and number of SMS sent) and of dose measures are shown in the supplemental tableS3. Results were similar to the self-reported data of the whole sample, with significant associations between duration of mobile phone calls and tiredness (OR: 1.37; 95%CI: 1.07 to 1.75) and lack of concentration (OR: 1.21; 95%CI: 1.03 to 1.44), respectively. Other significant associations were found for the volume of data traffic on the mobile phone and physical ill-being (OR: 1.42; 95%CI: 1.06 to 1.90) and for the number of SMS sent per day and lack of concentration (OR: 1.29; 95%CI: 1.04 to 1.61). Associations with the brain dose of the sample with operator data tended to be small and non-significant. The whole body dose of the sample with operator data, however, was significantly associated with all symptoms except for physical ill-being. We found a similar pattern when the exposures were based on three exposure categories (data not shown).

4. DISCUSSION

In cross-sectional and cohort analyses (a and b) increased health symptom reports were shown in relation to various wireless phone usage measures and whole body RF-EMF dose. Strongest associations were observed for the duration of data traffic on the mobile phone and number of text messages sent per day.

A particular strength of this study is the longitudinal design. Compared to a cross-sectional design, longitudinal studies allow for more robust conclusions. To the best of our knowledge, this is the first cohort study on non-specific symptoms in adolescents, using not only mobile phone call duration as an exposure proxy, but using RF-EMF dose measures derived from self-reported and objectively recorded mobile phone use data and propagation modelling. Our results of the cross-sectional analyses, where we found an increase in self-reported health symptom reports in relation to various self-reported usage measures, are in line with other cross-sectional studies on symptoms, mental health or sleeping problems (Byun et al. 2013; Ikeda et al. 2014; Koivusilta et al. 2007; Redmayne et al. 2013; Roser et al. 2016a; Schoeni et al. 2015b; Soderqvist et al. 2008).

In our cohort approach of the whole sample, the cross-sectional associations between symptoms and use of wireless communication devices could mostly be confirmed. The cohort analysis is less vulnerable to reverse causality and residual confounding since within person changes are considered. Strikingly, such a pattern was not observed in the only two other longitudinal studies on mobile phone use in adolescents and young adults. In these studies, less pronounced longitudinal associations with mental outcomes (Thomee et al. 2011) or cognitive functions (Thomas et al. 2010) were observed compared to their corresponding cross-sectional analyses. However, they were based on self-reported mobile phone call duration only. No study with operator recorded mobile phone use and symptoms has been conducted in adolescents so far and only one study was identified in adults (Frei et al. 2012). In this study of 1124 adults aged between 30 and 60 years, results of cross-sectional and cohort analyses were similar with a tendency of a negative correlation between symptoms and self-reported mobile phone use and no indication of an association for operator recorded mobile phone use, which was available for 451 study participants. This might suggest that not the use of mobile phone per se causes the symptoms but other factors associated with the use of mobile phones, which may be different for adults than adolescents, such as sleep deprivation due to night-time use, muscular tensions or lack of physical activity.

Self-reported mobile phone call duration is only modestly correlated to the actual mobile phone call duration in adolescents and recall and information bias is of concern (Aydin et al. 2011; Inyang et al. 2009; Vrijheid et al. 2009a). As seen in our study, self-reported mobile phone call duration is highly overestimated. Although objectively recorded mobile phone call duration seems to be more accurate, it may not represent the whole truth about mobile phone call duration in adolescents. Adolescents sometimes also make calls with phones other than their own to avoid costs. The use of other mobile phones is obviously not recorded in the objective mobile phone use data. However, according to the questionnaire, use of other people's mobile phone is not very common and contributes to about 12% of total mobile phone call duration. In our analyses, results for operator recorded and self-reported mobile phone usage measures were relatively similar, although effect estimates tended to be somewhat higher for the latter.

We put substantial emphasis on a comprehensive exposure assessment method, including most relevant RF-EMF sources and exposure relevant behaviours (Roser et al. 2015). We calculated effect estimates for various wireless device use variables and compared it with effect estimates of dose measures by calculating regression coefficients per interquartile range, which allows direct comparison. If there was a causal association between RF-EMF exposure and symptoms, one would expect more pronounced associations for RF-EMF dose measures compared to simple usage surrogates, as seen in the same study for memory performance (Schoeni et al. 2015a) but not for behavioural problems and concentration capacity (Roser et al. 2016b). Mostly for the whole body RF-EMF dose, but rarely for the brain dose, we found some significant associations in the cross-sectional, as well as in the cohort analyses. This pattern was particularly evident in the sample with operator data. Although objectively recorded mobile phone use has been used for dose calculation in this group, it has to be emphasized that the associations between whole body dose of the sample with operator data and symptoms are heavily driven by the self-reported duration of data traffic on the mobile phone (contributes over 20% to the whole body dose of the sample with operator data) and the self-reported use of computer/laptop/tablet connected to WLAN (29%). Strikingly, odds ratios for self-reported data traffic on the mobile phone (table 3) were considerably more pronounced than the odds ratio for whole body dose in the operator sample (table S3). This demonstrates that the significant associations for whole body dose in the operator samples are heavily driven by the strong associations of symptoms with self-reported data traffic but unlikely to be caused by RF-EMF exposure. Also in all other cross-sectional and cohort analyses, associations tended to be less pronounced for RF-EMF than for number of text messages sent or data traffic.

Chance findings cannot be ruled out since we have conducted 168 analyses. If a multiple testing correction were applied, one needs to consider the complex correlation structure between the outcomes and between the exposure variables. A Bonferroni correction would thus certainly be too conservative but a correction factor of 50 may be realistic. In this case the strongest observed associations ($p<0.001$) in the cohort analyses would still be significant such as the link between lack of energy and number of text sent or the association between exhaustibility and duration of data traffic on mobile phone (table 4). It has to be emphasized, however, that these analyses are not designed as independent tests but with the clear objective to evaluate the pattern of association with respect to the EMF exposure involved to various degrees in the exposure variables. This pattern would not be affected by any kind of multiple adjustment correction.

Uncertainty of the dose measure calculation cannot be quantified at that time. For example the absorbed radiation by the body depends on the unknown position of the emitting device in relation to the body. A further source of uncertainty is the emitted power from mobile phones, in particular during data traffic and in stand-by mode and errors in modelling and personal measurements (Roser et al. 2015).

The analyses in the sample with operator data have also some limitations. First, selection bias may be of concern, since only about 50% of the sample agreed to provide operator data. Second, operator recorded text messages (SMS) are most likely not relevant for the real texting behaviour of our study participants, since according to the questionnaire they use mostly web based applications such as “WhatsApp”. Thus, the strong associations between self-reported number of text messages and symptoms in both the cohort and the cross-sectional analyses are thus likely to be more accurate than the absence of associations seen for most symptoms in relation to operator recorded text messages. Third, it has to be emphasized, that the difference between the dose calculation in the whole sample and in the operator sample is restricted to duration of mobile phone use only (self-reported vs. operator recorded). This has a large impact on the brain dose calculation, where no indications for an association were seen in the operator sample, but not on the whole body dose, where operator recorded mobile phone use contributes only 20.0%. For all these reasons, we decided to use the whole sample analysis as the main analysis.

In summary, our study demonstrates that usage measures, such as the duration of data traffic on the mobile phone, or the number of texts sent per day are more consistently associated with symptoms than cumulative RF-EMF dose within one year or RF-EMF from transmitter as shown in Schoeni et al. (2016). This suggests that rather media use than RF-EMF exposure is related to non-specific symptoms in adolescents. A possible reason for increased health symptom reports related to wireless communication device use might be sleep deprivation. Mobile phone use in the evening or even during night may compete with sleeping hours which in turn might lead to more symptoms (Schoeni et al. 2015b). It was also shown that blue light emanating from the screens of the mobile phones has an impact on human sleep (Chellappa et al. 2013), and suppresses melatonin secretion (Vartanian et al. 2015). Circadian misalignment as a result of suppressed melatonin secretion caused by chronic artificial light at night may have negative effects on the psychological, cardiovascular and/or metabolic functions (Cho et al. 2015).

An alternative explanation for the observed association is residual confounding or reverse causality, which would mean that adolescents with symptoms (cross-sectional analyses) or more prone to develop symptoms (cohort analyses) are more likely to use wireless communication devices. would be that study participants find the constant accessibility and availability via mobile phones to be stressful which might lead to increased symptom reports. Thomee et al. (2011) found that perceived stressfulness of accessibility around the clock was the strongest predictor of mental health outcomes. We have seen in a previous cross-sectional analysis of our data that, independent of amount of mobile phone use, decreased well-being and behavioural problems were particularly pronounced in participants who scored high on the 10-item Problematic Mobile Phone Use Scale (Roser et al. 2016a). This scale was developed in the framework of addiction and measures and covers aspects such as loss of control, withdrawal and negative life consequences (Foerster et al. 2015). This may indicate that aspects of addiction may play a role for the observed associations.

5. Conclusion

In conclusion, this cohort study confirms associations between wireless communication device use and an increase in health symptom reports in adolescents previously seen in cross-sectional studies. The study suggest that other aspects of extensive media use cause symptoms and not RF-EMF, because associations were less pronounced for RF-EMF dose measures compared to various wireless device use variables such as texting or data traffic.

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Fig. 1. Results of the mixed-logistic cross-sectional analyses of baseline and follow-up data expressed as OR per interquartile change of the exposure variables. All models are adjusted for age, sex, nationality, school level, physical activity, alcohol and education of parents.
[a] number of study participants with symptoms / total number of study participants
All the numbers of these figures are shown in the supplemental table S1.

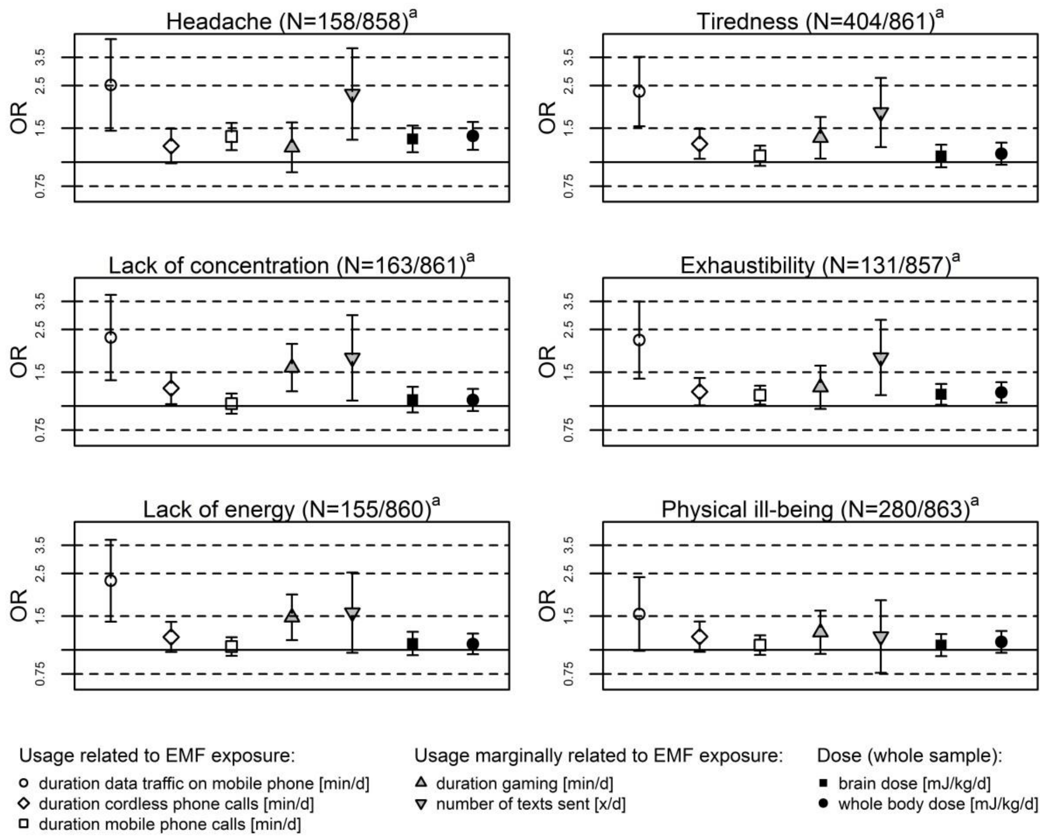

Fig. 2. Results of the cohort analyses expressed as OR per interquartile change of the exposure variables. All models are adjusted for age, sex, nationality, school level, physical activity, alcohol, education of parents, change in body height and time between baseline and follow-up investigation.
[a] number of study participants with occurrence of symptoms / total number of study participants
All the numbers of these figures are shown in Table 3.

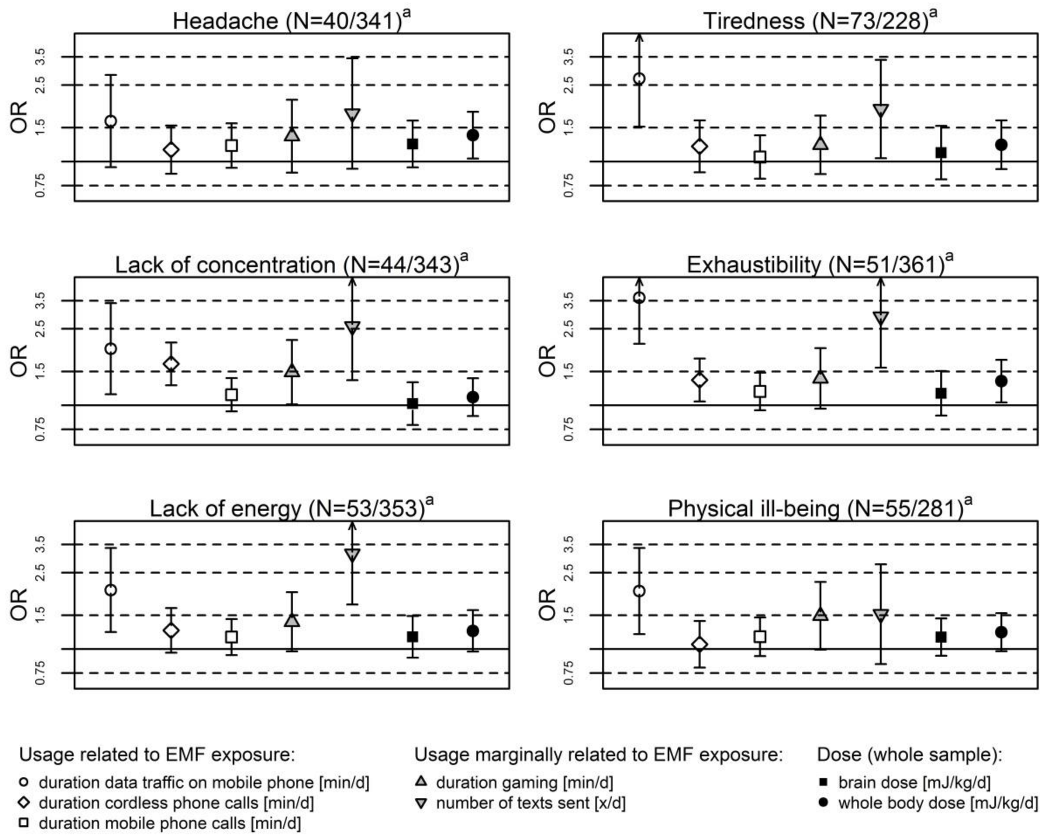

Table 1. Characteristics of the study participants at baseline and follow-up.

	Baseline	Follow-up
	N=439	N=425
	Mean (SD)	**Mean (SD)**
Age	14.0 (0.85)	15.0 (0.79)
Body height [cm]	163.7 (8.4)	167.3 (8.5)
	n (proportion)	**n (proportion)**
Male sex, n (%)	174 (39.6)	171 (40.2)
School level		
College preparatory high school	99 (22.5)	109 (25.6)
High School	340 (77.5)	316 (74.4)
Nationality		
Swiss	348 (79.3)	341 (80.2)
Swiss and other	62 (14.1)	59 (13.9)
Other	29 (6.6)	25 (5.9)
Physically active		
1-3 times per month or less	68 (15.5)	57 (13.4)
once per week	91 (20.7)	90 (21.2)
2-3 times per week	156 (35.5)	170 (40.0)
4-6 times per week	85 (19.4)	74 (17.4)
daily	39 (8.9)	34 (8.0)
Number of days with alcohol consumption		
None	304 (69.2)	223 (52.5)
One or less than one per month	99 (22.6)	105 (24.7)
2-4 times per month	33 (7.5)	78 (18.3)
2-3 times per week	3 (0.7)	19 (4.5)
Highest education of parents		
No education	3 (0.7)	2 (0.5)
Mandatory school/High school	14 (3.2)	14 (3.3)
Training school	221 (50.3)	215 (50.6)
College preparatory high school	33 (7.5)	32 (7.5)
College of higher education	132 (30.1)	127 (29.9)
University	36 (8.2)	35 (8.2)

Table 2. Different samples and their variables.

Whole sample	
	duration gaming [min/d], self-reported
	number of texts sent [x/d], self-reported
	duration data traffic on mobile phone [min/d], self-reported
	duration cordless phone calls [min/d], self-reported
	duration mobile phone calls [min/d], self-reported
	brain dose [mJ/kg/d]
	whole body dose [mJ/kg/d]
Sample with operator data	
	volume data traffic on mobile phone [MB/d], operator recorded
	duration mobile phone calls [min/d], operator recorded
	number of SMS sent [x/d], operator recorded
	brain dose [mJ/kg/d]
	whole body dose [mJ/kg/d]
Sample of subgroup	
	used for the development of the RF-EMF dose measures

Table 3. Descriptive statistics of all cumulative exposure and dose measures.

	mean	sd	median	max
Usage measures marginally related to RF-EMF exposure (negative control variables)				
duration gaming [min/d], self-reported	45.2	54.7	23.6	257.9
number of texts sent [x/d], self-reported	30.9	20.8	31.5	76.4
number of SMS sent [x/d], operator recorded	1.7	2.2	0.9	16.1
Usage measures related to RF-EMF exposure				
duration data traffic on mobile phone [min/d], self-reported	48.2	33.2	43.9	107.8
duration cordless phone calls [min/d], self-reported	7.3	7.6	4.8	53.1
duration mobile phone calls [min/d], self-reported	16.0	25.6	7.6	293.9
Objective usage measures related to RF-EMF exposure				
volume data traffic on mobile phone [MB/d], operator recorded	9.0	19.0	0.9	140.2
duration mobile phone calls [min/d], operator recorded	1.9	3.6	0.6	28.6
Dose (whole sample)				
brain [mJ/kg/d]	1421	1979	710	16233
whole body [mJ/kg/d]	322	431	205	6044
Dose (sample with operator data)				
brain [mJ/kg/d]	235	432	102	4787
whole body [mJ/kg/d]	125	87	107	756

Table 4. Results of the cohort analyses of the self-reported usage measures and dose measures for the whole sample. All odds ratios refer to an interquartile (IQR) increase in exposure.

	n with occurrence of symptoms / n total	IQR 25% [b]	75% [b]	Odds ratio crude (95% CI)	Odds ratio adjusted (95% CI) [c]
Usage measures marginally related to RF-EMF exposure (negative control variables)					
Headache					
duration gaming [min/d]	40/341	6.4	65.0	1.09 (0.75 to 1.59)	1.35 (0.88 to 2.09)
number of texts sent [x/d]	40/341	12.0	48.8	1.36 (0.75 to 2.46)	1.78 (0.92 to 3.44)
Tiredness					
duration gaming [min/d]	73/228	6.4	65.0	1.20 (0.90 to 1.61)	1.22 (0.86 to 1.73)
number of texts sent [x/d]	73/228	12.0	48.8	1.29 (0.79 to 2.11)	**1.87 (1.04 to 3.38)**
Lack of concentration					
duration gaming [min/d]	44/343	6.4	65.0	1.28 (0.94 to 1.75)	**1.49 (1.01 to 2.19)**
number of texts sent [x/d]	44/343	12.0	48.8	**2.30 (1.29 to 4.08)**	**2.57 (1.35 to 4.89)**
Exhaustibility					
duration gaming [min/d]	51/361	6.4	65.0	1.26 (0.93 to 1.69)	1.38 (0.96 to 1.98)
number of texts sent [x/d]	51/361	12.0	48.8	**2.00 (1.17 to 3.40)**	**2.89 (1.57 to 5.32)**
Lack of energy					
duration gaming [min/d]	53/353	6.4	65.0	1.26 (0.94 to 1.69)	1.39 (0.97 to 1.98)
number of texts sent [x/d]	53/353	12.0	48.8	**2.46 (1.44 to 4.20)**	**3.13 (1.71 to 5.75)**
Physical ill-being [a]					
duration gaming [min/d]	55/281	6.4	65.0	1.17 (0.85 to 1.60)	1.49 (0.99 to 2.24)
number of texts sent [x/d]	55/281	12.0	48.8	1.49 (0.88 to 2.53)	1.52 (0.84 to 2.76)
Usage measures related to RF-EMF exposure					
Headache					
duration data traffic on mobile phone [min/d]	40/341	22.5	74.3	1.38 (0.83 to 2.31)	1.62 (0.93 to 2.82)
duration cordless phone calls [min/d]	40/341	2.5	9.4	1.13 (0.86 to 1.47)	1.15 (0.86 to 1.54)
duration mobile phone calls [min/d]	40/341	3.0	18.6	1.16 (0.91 to 1.48)	1.21 (0.93 to 1.58)
Tiredness					
duration data traffic on mobile phone [min/d]	73/228	22.5	74.3	**1.69 (1.06 to 2.69)**	**2.70 (1.52 to 4.80)**
duration cordless phone calls [min/d]	73/228	2.5	9.4	1.14 (0.86 to 1.51)	1.20 (0.88 to 1.64)
duration mobile phone calls [min/d]	73/228	3.0	18.6	0.92 (0.73 to 1.16)	1.06 (0.81 to 1.37)
Lack of concentration					
duration data traffic on mobile phone [min/d]	44/343	22.5	74.3	**1.91 (1.17 to 3.14)**	**1.97 (1.14 to 3.40)**
duration cordless phone calls [min/d]	44/343	2.5	9.4	**1.67 (1.31 to 2.14)**	**1.64 (1.27 to 2.12)**
duration mobile phone calls [min/d]	44/343	3.0	18.6	1.17 (0.98 to 1.40)	1.14 (0.93 to 1.38)
Exhaustibility					
duration data traffic on mobile phone [min/d]	51/361	22.5	74.3	**2.56 (1.60 to 4.10)**	**3.63 (2.09 to 6.31)**
duration cordless phone calls [min/d]	51/361	2.5	9.4	**1.30 (1.02 to 1.65)**	**1.35 (1.05 to 1.75)**
duration mobile phone calls [min/d]	51/361	3.0	18.6	1.12 (0.92 to 1.36)	1.18 (0.94 to 1.48)
Lack of energy					
duration data traffic on mobile phone [min/d]	53/353	22.5	74.3	**1.87 (1.19 to 2.96)**	**2.03 (1.23 to 3.35)**
duration cordless phone calls [min/d]	53/353	2.5	9.4	1.25 (0.97 to 1.61)	1.25 (0.96 to 1.63)
duration mobile phone calls [min/d]	53/353	3.0	18.6	1.17 (0.97 to 1.42)	1.16 (0.93 to 1.43)
Physical ill-being [a]					
duration data traffic on mobile phone [min/d]	55/281	22.5	74.3	**2.15 (1.35 to 3.42)**	**2.00 (1.20 to 3.36)**
duration cordless phone calls [min/d]	55/281	2.5	9.4	1.13 (0.88 to 1.45)	1.06 (0.80 to 1.40)
duration mobile phone calls [min/d]	55/281	3.0	18.6	1.16 (0.96 to 1.40)	1.16 (0.92 to 1.46)
Cumulative Dose (whole sample)					
Headache					
brain [mJ/kg/d]	40/341	274.7	1853.6	1.20 (0.93 to 1.56)	1.23 (0.93 to 1.63)
whole body [mJ/kg/d]	40/341	120.1	380.3	**1.29 (1.004 to 1.67)**	**1.37 (1.04 to 1.81)**
Tiredness					
brain [mJ/kg/d]	73/228	274.7	1853.6	0.95 (0.71 to 1.25)	1.11 (0.81 to 1.53)
whole body [mJ/kg/d]	73/228	120.1	380.3	1.03 (0.80 to 1.32)	1.22 (0.91 to 1.64)
Lack of concentration					
brain [mJ/kg/d]	44/343	274.7	1853.6	1.08 (0.85 to 1.36)	1.02 (0.79 to 1.32)
whole body [mJ/kg/d]	44/343	120.1	380.3	1.14 (0.93 to 1.41)	1.10 (0.88 to 1.38)
Exhaustibility					
brain [mJ/kg/d]	51/361	274.7	1853.6	1.13 (0.88 to 1.45)	1.15 (0.88 to 1.51)
whole body [mJ/kg/d]	51/361	120.1	380.3	**1.26 (1.001 to 1.58)**	**1.34 (1.04 to 1.72)**
Lack of energy					
brain [mJ/kg/d]	53/353	274.7	1853.6	1.20 (0.95 to 1.51)	1.16 (0.90 to 1.49)
whole body [mJ/kg/d]	53/353	120.1	380.3	**1.26 (1.004 to 1.58)**	1.24 (0.97 to 1.59)
Physical ill-being [a]					
brain [mJ/kg/d]	55/281	274.7	1853.6	1.18 (0.96 to 1.44)	1.15 (0.92 to 1.44)
whole body [mJ/kg/d]	55/281	120.1	380.3	**1.24 (1.01 to 1.52)**	1.22 (0.98 to 1.54)

Odds ratios are expressed per inter quartile change of the exposure variables.

[a] Kidscreen well-being inverted to ill-being for coherent data presentation.

[b] 25^{th} and 75^{th} percentile, respectively. IQR: inter quartile range.

[c] adjusted for age, sex, nationality, school level, physical activity, alcohol, education of parents, change in body height and time between baseline and follow-up investigation.