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Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents

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Abstract Only few studies have so far investigated possible health effects of radio-frequency electromagnetic fields (RF EMF) in children and adolescents, although experts discuss a potential higher vulnerability to such fields. We aimed to investigate a possible association between measured exposure to RF EMF fields and behavioural problems in children and adolescents. 1,498 children and 1,524 adolescents were randomly selected from the population registries of four Bavarian (South of Germany) cities. During an Interview data on participants' mental health, socio-demographic characteristics and potential confounders were collected. Mental health behaviour was assessed using the German version of the Strengths and Difficulties Questionnaire (SDQ). Using a personal dosimeter, we obtained radiofrequency EMF exposure profiles over 24 h. Exposure levels over waking hours were expressed as mean percentage of the reference level. Overall, exposure to radiofrequency electromagnetic fields was far below the reference level. Seven percent of the children and 5% of the adolescents showed an abnormal mental behaviour. In the multiple logistic regression analyses measured exposure to RF fields in the highest quartile was associated to overall behavioural problems for adolescents (OR 2.2; 95% CI 1.1–4.5) but not for children (1.3; 0.7–2.6). These results are mainly driven by one subscale, as the results showed an association between exposure and conduct problems for adolescents (3.7; 1.6–8.4) and children (2.9; 1.4–5.9). As this is one of the first studies that investigated an association between exposure to mobile telecommunication networks and mental health behaviour more studies using personal dosimetry are warranted to confirm these findings.

Keywords Behavioural problems · Radio-frequency electromagnetic fields · Children · Adolescents · SDQ · Dosimetry

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Introduction

Despite the increase of mobile phone use in the last decade and the growing concern whether radiofrequency (RF) fields adversely affect health and well-being, only few studies have been published that focussed on children and adolescents [1–5].

However, especially children and adolescents are important in the discussion of potential adverse health effects because of their possibly higher vulnerability to high-frequency electromagnetic fields. Young people might be more vulnerable due to their still developing nervous systems and the potential for higher cumulative RF exposure during their lifetimes [6–8].

The few studies that investigated a possible association between exposure to RF fields and health outcomes in children and adolescents focused mainly on perceived health. In these studies, self-reported use of mobile phones was associated with poor perceived health [1–3]. However, reporting bias and confounding might have been a problem.

One recent study examined the association between mobile phone exposure and behavioural problems. The

authors of this analysis asked mothers about their use of mobile phones during pregnancy and the current mobile phone use of their children. In parallel, mental health behaviour was assessed using the Strengths and Difficulties Questionnaire (SDQ). The results of this study showed a statistically significant adverse effect of self-reported prenatal and postnatal exposure to RF fields and behavioural problems in children [9]. Behavioural problems in children and adolescents are nowadays of special interest, as the number of children and adolescents being diagnosed with e.g. attention deficit hyperactivity disorder (ADHD) increases [10].

In the present analysis, we investigated the possible effects of exposure to RF EMF fields assessed using personal dosimetry on mental health behaviour in Bavarian (Southern Germany) children and adolescents.

Materials and methods

Study design and participants

The study took place in four Bavarian cities with different population sizes. Between 2006 and 2008 the participants were recruited randomly from the registration offices of these four towns and invited to participate in the study. Overall, 1,498 children (aged between 8 and 12 years) and 1,524 adolescents (aged between 13 and 17 years) were included.

All potential participants were invited in written form and asked to fill in a short-questionnaire irrespective of their participation in the study. The information from the questionnaire were used for a non responder analysis to assess potential selection bias. Those children and adolescents respectively their parents who declared consent were invited to a local study centre, where they completed a Computer Assisted Personal Interview (CAPI) on participants' well-being, socio-demographic characteristics and potential confounders. In case of the children one parent was also invited and completed an interview. After the interview the children and adolescents obtained the ESM-140 mobile phone dosimeter for a 24-h measurement. Further details of the design have been described earlier [11].

Study instruments

Mental health

During the interview 25 questions about mental health behaviour were asked following the German version of the Strengths and Difficulties Questionnaire (SDQ). For the children and adolescents we used the self-report version of the SDQ. In case of the children, we also used a parental version. This questionnaire includes the same 25 items as in the self-report version for the children, but is completed by the parents.

The 25 items of the questionnaires are divided between 5 scales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviour. All scales comprises 5 items with three possible answer categories ("certainly true", "somewhat true", "not true") ranging between 0 and 2 points. Using the sum of the answer-values a range between 0 and 10 points can be reached for each of the 5 scales. To specify the overall difficulties score the four scales that refer to the behavioural problems are summed up to a score between 0 and 40 points. The prosocial scale is disregarded.

For each scale as well as for the total difficulties score the participants are classified as "normal", "borderline" or "abnormal" as described in [12–14]. Due to the small numbers of children and adolescents that were classified as "borderline", we dichotomised the outcome for the analysis ("normal" vs. "borderline/abnormal").

Potential confounding variables

Sociodemographic data [15], the four study towns, self estimated environmental worries and the self estimated general exposure to RF EMF fields taken from the CAPI were considered as potential confounders. Age and level of education were dichotomised:

Age

- 8–10 and 11–12 years (children)
- 13–15 and 16–17 years (adolescents)

Level of education

- at least 12 years of education (parents of the children)
- at least grammar school ("Gymnasium"; adolescents)

Environmental worries were assessed during the CAPI for the parents of the children and for the adolescents themselves with a short form of the environmental worry scale [16, 17]. The scael consists of 12 questions about general and specific environmental worries. Participants were divided into two groups ("not worried" and "worried).

Participants were also asked to estimate their general use of mobile and cordless phones (<nearly daily vs. at least nearly daily). Furthermore they should estimate the distance of their home to the next mobile phone base station (<500 m away vs. ≥500 m away). These questions were taken from the questionnaire of the annual survey of the Institute for applied sciences (infas) [18].

Exposure assessment

Exposure was measured using the personal dosimeter ESM-140 (Maschek Electronics) and was assessed every second resulting in 86.400 measurements over 24 h. The following frequency ranges were covered [11]:

- GSM 900 (up and down link)
- GSM 1800 (up and down link) including Universal Mobile Telecommunication System (UMTS 2100) and Digital Enhanced Cordless Telecommunications (DECT)
- Wireless local area network (WLAN 2400) frequencies.

For the exposure assessment, a combination of the frequency bands had to be used as the dosimeter has a low selectivity between up- and down-link channels.

During nighttimes the dosimeter was fixed on a bottle filled with water. Due to the physical characteristics of the dosimeter valid measurements can only be obtained if the dosimeter is moved. Therefore night-time values were excluded and only exposure levels during individual waking hours were considered.

The overall exposure during these hours was summarized as average field strengths in percentage of the ICNIRP (International Commission on Non-Ionizing Radiation Protection) reference level [11].

Statistical analysis

For the analysis 30 participants had to be excluded due to missing interview data or technical errors of the measurements. Thus, data of 1,484 children and 1,508 adolescents could be used.

To analyze a potential association between exposure to RF fields and mental health, the mean percentage of the ICNIRP reference level during waking hours was used. Measured exposure was divided into quartiles enabling to assess a possible dose-response-relationship. We could not take exposure as a continuous variable, because too many values were below the limit of determination.

Multivariate analyses were done using logistic regression models stratified for children and adolescents. The models were adjusted for age, sex, level of education, self reported environmental worries, self reported general RF exposure and study place.

In case of the children, Odds Ratios for the concordant ratings between children and parents were calculated. Therefore, we restricted the analysis to those children where the self-assessment of the child was concordant with the parental report; discordant ratings were excluded.

As it might be that the observed outcome (behavioural problems) causes more extensive mobile phone use (reversed causality) we did a sensitivity analysis restricted to children and adolescents who did not use a mobile phone.

Statistical analyses were carried out using SAS (SAS version 9.1; SAS Institute Inc., Cary, NC, USA).

Results

Descriptive data

Overall 6.386 children and adolescents were invited, of which 5.870 were eligible for the study. 4.452 persons (76%) answered the short questionnaire. 1,498 children (aged between 8 and 12 years) and 1,524 adolescents (aged between 13 and 17 years) participated in the interview and the exposure measurement (52% of those who were eligible for the study).

The adolescents and the parents of the children were more likely to have a higher level of education. Half of the children and nearly every adolescent (92%) owned a mobile phone. Most of the children (96%) and also the majority of adolescents did not use their mobile phone daily (77%). Regarding the use of a cordless phone, most of the children used the phone infrequently (72%), whereas 55% of the adolescents used the cordless phone at least nearly daily. Sixty-five percent of the adolescents and 67% of the parents of the children estimated the distance between their residence and the next mobile phone base station as less than 500 m (Table 1).

Exposure to mobile phone frequencies assessed using personal dosimetry was far below the reference limit and ranged from a mean of 0.13% (all measurement values below the limit of determination) to a mean of 0.92% of the ICNIRP reference level per second during waking hours. Median exposure was slightly higher for adolescents (0.19% of the reference level) than for children (0.18% of the reference level) (Table 1) [11].

Mental health behaviour

Children showed a slightly higher prevalence of abnormal overall behaviour (7%) than adolescents (5%) (Table 2). The same was seen for conduct problems and peer relationship problems. However, the prevalence of emotional problems was higher in adolescents (6%) than in children (3%). Four percent of the children and 5% of the adolescents were categorized as hyperactive.

Besides for peer relationship problems, parents assessed a higher prevalence of all mental health behavioural scales for their children than the children themselves (Table 2).

The overall agreement between children and their parents ranged between 75% (emotional problems) and 90% (peer relationship problems) (Table 3).

Table 1 Descriptive data of the children and the adolescents

Variable	Children prevalence *n* (%) *n* = 1,484	Adolescents prevalence *n* (%) *n* = 1,508
Age		
11–12 years respecively 16–17 years	693 (46.7)	545 (36.1)
Sex		
Male	724 (48.9)	731 (48.5)
Level of education		
At least 12 years of education resp.	939 (64.1)[a]	771 (51.4)
At least grammar school		
Mobile phone ownership	747 (50.4)	1506 (91.4)
General use of a mobile phone		
<Nearly daily	1419 (95.8)	1156 (76.9)
At least nearly daily	61 (4.2)	348 (23.1)
General use of a cordless phone		
<Nearly daily	1066 (71.8)	672 (44.6)
At least nearly daily	416 (28.2)	835 (55.4)
Self-estimated distance to the next base station		
<500 m	946 (67.1)	922 (64.7)
≥500 m	464 (32.9)	503 (35.3)
Exposure during waking hours (% ICNIRP-reference level)		
Range	0.13–0.92	0.13–0.78
Quartiles	0.15	0.15
	0.17	0.17
	0.20	0.21
Mean (standard deviation)	0.18 (0.06)	0.19 (0.06)

[a] Data of the parents of the children

Table 2 Prevalence of abnormal behaviour assessed by the German version of the SDQ, stratified for age group and report version

Scale	Adolescents[a] *n* (%)	Children[a] *n* (%)	Parents of the children[b] *n* (%)
Overall behavioural problems	80 (5.3)	107 (7.2)	257 (17.4)
Emotional problems	86 (5.7)	51 (3.4)	387 (26.2)
Conduct problems	68 (4.5)	95 (6.4)	356 (24.1)
Hyperactivity	69 (4.6)	64 (4.3)	193 (13.1)
Peer relationship problems	72 (4.8)	109 (7.4)	93 (6.3)

[a] Self-report version of the SDQ for children and adolescents

[b] Parental version of the SDQ completed for their children

Association between exposure and mental health behaviour

Adolescents with an exposure in the highest quartile reported more frequently overall behavioural problems (OR 2.2; 95% CI 1.1–4.5) than adolescents with an exposure in the remaining three quartiles (Table 4).

Furthermore, an association between exposure to measured RF fields and conduct problems was seen both for the children (2.9; 1.4–5.9) and for the adolescents (3.7; 1.6–8.4). Restricting the analysis to those children whose self-report was concordant with the parental report, the same tendency was observed. However, due to the lower sample size results were not statistically significant (Table 4). Neither for children nor for adolescents was an association between measured exposure and emotional problems, hyperactivity or peer relationship problems observed.

As measured exposure and subjective exposure (self-reported mobile phone and cordless phone use, self-estimated distance to the next mobile phone base station) might be correlated, we conducted also multivariate

Table 3 Accordance between data of the parents' report and self-report of the children

	Accordance (%)	
	Normal behaviour	Abnormal behaviour
Overall behavioural problems	79	4
Emotional problems	73	2
Conduct problems	73	3
Hyperactivity	84	22
Peer relationship problems	88	2

analyses without the variables for subjective exposure as potential confounders. No difference in the results could be seen (data not shown).

Discussion

This study is the first of its kind to investigate a possible association between exposure to RF EMF fields and well-being including mental health behaviour in children and adolescents using personal dosimetry for the exposure assessment.

In comparison to another German study, parents reported a similar prevalence of total difficulties for their children [19]. In two Norwegian studies that also used the self-report version in adolescents, the prevalence of behavioural problems was lower than in our study [20, 21]. This might be due to differences in the German and Norwegian cut-offs for the single questionnaire-scales or also due to cultural differences between the countries.

The SDQ is stated to be a reliable instrument for health behaviour problems when data of at least two informants can be used [22, 23]. As we collected the information of the children as well as information of one parent, we used these data for a sensitivity analysis. The results showed no association between exposure to RF fields and behavioural problems in children. Nevertheless, the results were comparable to those of the main analysis. Thus, we assume that the results for the adolescents were reliable as well, despite the fact that only data of the self-reported version of the SDQ was available for this group.

As the design of the study was cross-sectional, the measured exposure and the considered mental health behaviour outcomes were only assessed once. Therefore a misclassification concerning the outcome is possible. It might be the case that the participants over- or underreported possible behavioural problems. As the participants were not aware of their actual measured exposure level differential misclassification is unlikely. Thus, an underestimation of the exposure-response-relationship might be possible [24–26].

Considering the time dependent effort, participation in the study was quite good (52%). However, it was seen in a non-responder analysis that mainly those participated who were concerned about potential health effects due to RF EMF exposure. Thus a preferential selection bias might be possible. Due to the objectively measured exposure the participants were not aware of their true exposure over the study day and thus, an overestimation of the outcome is unlikely.

The overall exposure levels were on average less than 1% of the ICNIRP reference level. This result is in agreement with other studies [27, 28]. It would have been interesting to restrict the analysis to the three mobile phone bands. However, due to a low selectivity of the frequency bands—the 1,800 MHz frequency band included GSM 1800, UMTS and DECT—a differentiation was not possible.

Although exposure levels were low, an association between measured exposure and total behavioural problems for the adolescents was seen. Furthermore, we observed an association between measured exposure and conduct problems for children and adolescents. As we did not have data on parameters like e.g. family psychiatric history or data on pregnancy of the mother that are discussed as potential risk factors in the context of behavioural outcomes like hyperactivity [29] it might be that unmeasured confounding produced our results. Furthermore, up to now there is no known biologic mechanism to explain an association between exposure to radiofrequency fields and behavioural problems as observed in our study.

It might be that the observed outcome (behavioural problems) causes more extensive mobile phone use (reversed causality). We therefore tested for interaction between exposure and mobile phone use. The interaction terms did not reach the level of statistical significance for children and adolescents, indicating that the observed association was true independent of mobile phone use.

Up to now there is only one other study published, that investigated the association between exposure to cell phones and behavioural problems in children. The results of Divan et al. [9] indicated that reported mobile phone use might be associated with behavioural problems. The authors contribute that the results might also be produced by unmeasured confounders.

Conclusions

In summary, this is the first study that investigated a possible association between measured exposure to RF EMF fields and behavioural problems in children and adolescents. We observed an association between measured exposure and behavioural problems for the children and the

Table 4 Adjusted logistic regression for the association between exposure to mobile telecommunication networks and behavioural problems in children and adolescents

Exposure	Adolescents ($n = 1508$)[a]		Children ($n = 1484$)[a]		Concordant ratings children and parents[a]	
	Prevalence (abnormal behaviour) *n* (%)	OR (95% CI)	Prevalence (abnormal behaviour) *n* (%)	OR (95% CI)	Prevalence (abnormal behaviour) *n* (%)[b]	OR (95% CI)
Total behavioural problems						
1st Quartile	19 (5.0)	1.0	30 (8.1)	1.0	16 (5.3)	1.0
2nd Quartile	17 (4.5)	0.9 (0.5–1.9)	21 (5.7)	0.8 (0.4–1.5)	11 (3.7)	0.7 (0.3–1.7)
3rd Quartile	15 (4.0)	1.0 (0.5–2.1)	25 (6.7)	1.0 (0.5–1.9)	14 (4.4)	1.0 (0.4–2.3)
4th Quartile	29 (7.7)	2.2 (1.1–4.5)	31 (8.4)	1.3 (0.7–2.6)	15 (4.9)	1.0 (0.4–2.4)
Emotional symptoms						
1st Quartile	24 (6.4)	1.0	13 (3.5)	1.0	9 (3.3)	1.0
2nd Quartile	18 (4.8)	0.8 (0.4–1.7)	13 (3.5)	0.9 (0.4–2.0)	7 (2.6)	0.7 (0.2–1.9)
3rd Quartile	18 (4.8)	0.6 (0.3–1.3)	11 (3.0)	0.6 (0.2–1.5)	5 (1.8)	0.4 (0.1–1.4)
4th Quartile	26 (6.9)	1.1 (0.5–2.2)	14 (3.8)	0.7 (0.3–1.9)	10 (3.6)	0.7 (0.2–2.3)
Conduct problems						
1st Quartile	10 (2.7)	1.0	19 (5.2)	1.0	10 (3.7)	1.0
2nd Quartile	7 (1.9)	0.6 (0.2–1.7)	20 (5.4)	1.1 (0.5–2.3)	9 (3.1)	0.7 (0.2–2.1)
3rd Quartile	18 (4.8)	1.9 (0.8–4.5)	19 (5.1)	1.2 (0.6–2.5)	11 (3.9)	1.2 (0.4–3.4)
4th Quartile	33 (8.8)	3.7 (1.6–8.4)	37 (10.0)	2.9 (1.4–5.9)	19 (6.9)	2.3 (0.8–6.4)
Hyperactivity						
1st Quartile	12 (3.2)	1.0	18 (4.9)	1.0	6 (1.9)	1.0
2nd Quartile	18 (4.8)	1.7 (0.8–3.7)	13 (3.5)	0.7 (0.3–1.5)	4 (1.3)	0.5 (0.1–2.0)
3rd Quartile	20 (5.3)	2.0 (0.9–4.5)	12 (3.2)	0.6 (0.2–1.3)	8 (2.5)	1.3 (0.4–4.5)
4th Quartile	19 (5.1)	2.1 (0.9–4.8)	21 (5.7)	1.1 (0.5–2.6)	5 (1.6)	0.9 (0.2–3.5)
Peer relationship problems						
1st Quartile	21 (5.6)	1.0	27 (7.3)	1.0	7 (2.1)	1.0
2nd Quartile	18 (4.8)	0.8 (0.4–1.5)	22 (6.0)	0.8 (0.4–1.5)	7 (2.1)	1.0 (0.3–3.7)
3rd Quartile	13 (3.5)	1.1 (0.5–2.1)	25 (6.7)	1.0 (0.5–2.0)	9 (2.6)	1.7 (0.5–5.7)
4th Quartile	20 (5.3)	1.4 (0.7–2.7)	35 (9.4)	1.4 (0.7–2.7)	8 (2.5)	1.4 (0.4–5.3)

Adjusted for age, sex, level of education (in case of children the level of education of their parents), study town, environmental worries and the self estimated exposure to mobile phone frequencies

OR odds ratio, *95% CI* 95% confidence interval

[a] *n* differs between the different scales

[b] Concordant ratings of the children and the parents

adolescents. Due to the fact that there is no known biological mechanism and behavioural problems were only assessed once, more studies are warranted to confirm the findings. A cohort study including a clinical confirmation of the diagnosis would be desirable to determine the temporal sequence of exposure to mobile telecommunication networks and mental health behaviour.

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