Prenatal and Postnatal Exposure to Cell Phone Use and Behavioral Problems in Children

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Background: The World Health Organization has emphasized the need for research into the possible effects of radiofrequency fields in children. We examined the association between prenatal and postnatal exposure to cell phones and behavioral problems in young children.

Methods: Mothers were recruited to the Danish National Birth Cohort early in pregnancy. When the children of those pregnancies reached 7 years of age in 2005 and 2006, mothers were asked to complete a questionnaire regarding the current health and behavioral status of children, as well as past exposure to cell phone use. Mothers evaluated the child's behavior problems using the Strength and Difficulties Questionnaire.

Results: Mothers of 13,159 children completed the follow-up questionnaire reporting their use of cell phones during pregnancy as well as current cell phone use by the child. Greater odds ratios for behavioral problems were observed for children who had possible prenatal or postnatal exposure to cell phone use. After adjustment for potential confounders, the odds ratio for a higher overall behavioral problems score was 1.80 (95% confidence interval = 1.45–2.23) in children with both prenatal and postnatal exposure to cell phones.

Conclusions: Exposure to cell phones prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry. These associations may be noncausal and may be due to unmeasured confounding. If real, they would be of public health concern given the widespread use of this technology.

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Exposure to radiofrequency fields is increasingly common, but the potential influence on health has not been thoroughly investigated, especially in children. Between 2003 and 2008, there were more than 900 million new cell phone subscribers worldwide, with a total of more than 2 billion subscribers.[1] Fetuses and children may be more vulnerable than adults to external exposures in general.[2] In 2000, the Stewart Report recommended a precautionary approach to the use of cell phones until more detailed and scientifically robust information became available, especially for children.[3] Numerous reviews, including 1 by the World Health Organization,[4] stress the need for studies in children and on cognitive effects, because of the importance of cognitive abilities and learning in early development.

Most epidemiologic studies of exposure to radiofrequency fields have focused on brain and acoustic cancers as outcomes[5–11] or on subjective symptoms such as headaches.[12,13] A number of laboratory studies have examined physiologic effects after short-term exposure,[14–18] but a variety of other outcomes are yet to be investigated, and none has included potentially susceptible populations such as fetuses and very young children.

Children are potentially exposed during fetal life by maternal use of cell phones and then later in childhood when they themselves become users of cell phones. Exposures early in life may have particular importance because this is during vulnerable stages of brain development.

There is limited information on the association between radiofrequency field exposure during pregnancy and reproductive outcomes (spontaneous abortions, birth weight, sex ratio, and congenital malformations), mostly from occupational studies. Occupational exposures are typically much higher than exposures from cell phone use. Some studies have reported increased risk of spontaneous abortions and congenital malformations, although these results come from poorly designed studies.[19]

Since no established mechanism is known for radiofrequency exposure—except for what may be caused by an increased temperature in the exposed regions—it is impossible to exclude any health outcomes from consideration. Experimental research indicates exposure might affect nonspecific neurologic performance such as attention. In a preliminary cross-sectional analysis of 13 year-olds in the MoRPhEUs study, differences in certain cognitive abilities related to cell phone use were observed (Rodney Croft personal communication, 16 December 2007).

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An increasing number of children are being diagnosed with attention-deficit hyperactivity disorder (ADHD) as classified in the DSM-IV or hyperkinetic disorder in the ICD-10 classification. These behavioral problems include hyperactivity, impulsivity, and difficulty in concentrating. Known risk factors for these conditions include sex of child, smoking during pregnancy, family psychiatric history, and socioeconomic status (SES).[20,21] To date, no epidemiologic studies have investigated cell phone use as a possible risk factor for behavioral outcomes with similarities to ADHD.

In this analysis, we explored the association of cell phone use during pregnancy and during early childhood with behavioral problems in children.

METHODS

This study was based on the Danish National Birth Cohort, which recruited study participants from March 1996 through November 2002. A total of 101,032 pregnancies were enrolled in the cohort.[22,23] Mothers and live-born children constitute 2 fixed cohorts that are to be followed for decades in a life-course perspective. Detailed information on life-style factors, dietary habits and environmental exposures were collected by means of 4 telephone interviews; 2 of these were conducted during pregnancy and 2 when the newborn child reached 6 and 18 months of age.[24]

A new round of data collection from mothers that focuses upon the child's health status was initiated when the children reached the age of 7 years. This analysis is based on the information collected about children born between 1997 and 1999. This Age-7 Questionnaire contained questions on cell phone use among children, as well as among mothers during pregnancy. In addition, the questionnaire included data on social conditions, family lifestyle, and diseases in childhood, including behavioral problems as defined by the Strengths and Difficulties Questionnaire. Specifically, we asked about mother's use of cell phone during pregnancy (the number of times spoken per day, proportion of time the phone was on), use of hands-free equipment during pregnancy (proportion of time) and location of the phone when not in use (handbag or clothing pocket), and for children, current use of cellular and other wireless phones.

Letters were sent to participants' homes instructing them about how to respond to the questionnaire via the Internet, as well as informing them that they may request a questionnaire to return by ordinary mail using a prepaid envelope. If they did not respond within a 4-week period, a reminder letter was sent. If, at the end of a second 4-week period, the Internet version still had not been completed, a paper-based questionnaire was provided via mail. Formats of the 2 questionnaire were identical.

This study was approved by the Danish Data Protection Agency and by regional science ethics committees in Denmark as well as the University of California, Los Angeles Office for the Protection of Research Subjects.

Outcome Measures

Behavioral problems in children were assessed using the Strengths and Difficulties Questionnaire.[25,26] Mothers completed a list of 25 questions with scaled responses (very true, partly true, or not true) regarding their child's behavior. The assessment of disorders was based upon scores over a particular group of questions with a priori defined cutoff points. The questionnaire assessed overall behavioral problems or disorders, as well as specific emotional, conduct, hyperactivity, peer and social disorders.

Based on the specific numerical score, children were classified as abnormal, borderline, or normal for overall behavioral problems as well as for the specific outcomes such as emotional, conduct, hyperactivity, or peer problems.[27]

Statistical Analysis

Comparisons were made between baseline characteristics (ie, sex of child, social-occupational status, and mother's psychiatric history and smoking) as well as prenatal and postnatal cell phone exposure.

We used an ordinal logistic regression model (adjacent category logistic model) to estimate the odds of the outcomes of behavioral problems (2 = abnormal, 1 = borderline, 0 = normal) in children according to combined prenatal and postnatal exposure to cell phones, prenatal exposure only, and postnatal exposure only. The model imposes the same odds in going from "normal" to "borderline" as from "borderline" to "abnormal." Tests for heterogeneity were conducted to verify this assumption. Regression analyses were adjusted for several potential confounders (child's sex, mother's age, mother's psychiatric history, social-occupational status, and smoking during pregnancy). We computed odds ratios (ORs) and 95% confidence intervals (CIs).

To evaluate possible dose-response patterns, we considered proxies of prenatal exposure intensity (times per day spoken, location of the phone when not in use, proportion of time the phone was turned on, and use of an earpiece with cell phone). For each specific characteristic of use, the reference category was defined as the lowest possible category (ie, no use, 0–1 times per day spoken). For location of phone when not in use, the reference category was "carried in bag" versus "carried in dress/pant pocket."

RESULTS

Mothers completed an Age-7 Questionnaire for 13,159 children, which is about 65% of the eligible mothers who were contacted through November 2006. Thirty percent of children were using a cell phone at the age of 7 years, but fewer than 1% used a cell phone for more than 1 hour per week. About 11% of children were exposed to cell phones both prenatally and postnatally (Table 1). Nearly half had neither prenatal nor postnatal exposure, and another 8% (n = 1091) were coded as do not know or missing in the analysis

TABLE 1. Distribution of Covariates and Behavioral Problems Score by Prenatal and Postnatal Exposure to Cell Phone Use (n = 13,159)

	No Exposure (n = 6471)	Prenatal Exposure Only[a] (n = 1895)	Postnatal Exposure Only[b] (n = 2281)	Both Prenatal and Postnatal (n = 1421)	Do Not Know/Missing (n = 1091)
Covariates					
Sex of child					
Boy	53.3	53.6	47.0	46.7	51.2
Girl	46.6	46.4	52.9	53.1	48.8
Missing	0.1	0.0	0.1	0.2	0.0
Social-occupational status					
High	53.5	50.9	52.1	45.3	48.6
Medium	35.2	36.4	36.7	38.9	38.3
Low	7.5	10.0	7.3	12.1	9.9
Missing	3.8	2.7	3.9	3.7	3.2
Mother ever suffered from mental disorder or neurosis					
Yes	5.2	5.9	6.6	8.0	12.6
No	91.1	91.5	89.7	88.8	84.6
Do not know/missing	3.7	2.6	3.7	3.2	2.8
Mother ever had psychiatric illness					
Yes	10.1	11.9	13.5	16.8	34.7
No	87.7	84.9	83.9	81.0	57.7
Do not know	1.6	2.2	1.8	1.6	1.5
Missing	0.6	1.0	0.8	0.6	6.1
Mother's smoking status during pregnancy					
Entire pregnancy	15.1	19.3	20.4	24.8	17.0
Every day	80.0	85.0	79.6	83.0	82.7
Less than every day	10.6	5.5	12.0	7.4	6.5
Do not know frequency	9.4	9.6	8.4	9.6	10.8
Early in pregnancy only	6.5	6.2	7.3	8.2	7.3
Not a smoker	72.5	69.2	66.7	59.9	70.1
Do not know/missing	5.9	5.3	5.6	7.1	5.6
Behavioral problems score					
Overall behavioral problems score					
Normal (0–13)	95.0	91.6	93.8	89.9	89.5
Borderline (14–16)	2.5	4.1	3.7	5.4	3.6
Abnormal (17–40)	2.4	4.2	2.4	4.6	2.7
Missing	0.1	0.1	0.1	0.1	4.2
Emotional symptoms score					
Normal (0–3)	87.8	85.5	86.5	82.8	79.9
Borderline (4)	6.0	6.0	6.6	7.9	7.6
Abnormal (5–10)	6.1	8.4	6.9	9.2	8.4
Missing	0.1	0..1	0.0	0.1	4.1
Conduct problems score					
Normal (0–2)	87.1	83.9	86.4	80.2	81.3
Borderline (3)	8.1	9.9	8.7	11.1	8.9
Abnormal (4–10)	4.7	6.1	4.9	8.7	5.6
Missing	0.1	0.1	0.0	0.0	4.2
Hyperactivity score					
Normal (0–5)	91.8	88.9	91.8	88.1	87.6
Borderline (6)	3.5	4.5	3.3	4.3	3.2
Abnormal (7–10)	4.7	6.5	4.9	7.5	5.0
Missing	0.1	0.1	0.0	0.1	4.1
Peer problems score					
Normal (0–2)	92.5	90.0	91.6	89.1	88.5
Borderline (3)	3.5	4.3	4.6	5.2	3.7
Abnormal (4–10)	4.0	5.6	3.7	5.6	3.7
Missing	0.1	0.1	0.1	0.1	4.2

Values are given in percentage.
[a]Mother's use during pregnancy.
[b]Child's use.

because of incomplete information regarding mother's or child's cell phone use. For most characteristics and outcomes, the percent missing or not known was small (0%–7%) and similar across the 4 exposure groups. One exception was the percentage of mothers ever having psychiatric illness; nearly 35% of the 1091 who had incomplete information on exposure to cell phones answered "Yes" to this question. Nearly 90% of the children were reported as "normal" for all types of behaviors. Children with exposure to cell phones (prenatally, postnatally, or both) tended to have higher percentages of borderline or abnormal scores for emotional symptoms, conduct problems hyperactivity and peer problems.

The highest odds ratios for behavioral problems were observed for children who had both prenatal and postnatal exposure to cell phones compared with those who were not exposed during either time period (Table 2). For these children the adjusted OR for the overall behavioral score was 1.80 (95% CI = 1.45–2.23). For prenatal or postnatal exposure only, the adjusted odds ratios were 1.54 (1.32–1.81) and 1.18 (1.01–1.38), respectively. Adjusting for potential confounders moved the results towards the null.

For the combined prenatal and postnatal exposure, adjusted odds ratios (Table 3) were similarly increased for each of the 4 specific behavioral outcomes. The odds ratios were higher for prenatal exposure than for postnatal exposure, for each of the behavioral problems.

When analyses were stratified by the covariates the associations between cell phone use and behavioral problems were stable across the strata (Table 4). Associations with overall behavioral problems in children did not vary when considering the questionnaire administration format (paper-based or Internet-based) (data not shown).

Almost 85% of mothers carried their cell phone in a bag during pregnancy rather than on their person or elsewhere, and nearly 82% reported not using an earpiece (data not shown). In Table 5, nearly 56% of children with prenatal exposure had mothers who reported speaking 0–1 times per day during their pregnancy and 43% reported having the phone turned on at all times. For prenatal exposures—regardless of postnatal exposure—odds ratios for the overall behavioral problems score tended to be greater with higher potential for fetal exposure; however,

TABLE 2. Association of Prenatal and Postnatal Exposure to Cell Phone Use With Overall Behavioral Problems Score

	Postnatal Exposure					
	No		Yes		Prenatal Exposure[a]	
	Unadjusted OR	Adjusted OR (95% CI)[b]	Unadjusted OR	Adjusted OR (95% CI)[b]	Unadjusted OR	Adjusted OR (95% CI)[b]
Prenatal exposure						
No	1.0[c]	1.0[c]	1.25	1.18 (0.96–1.45)	1.0[c]	1.0[c]
Yes	1.77	1.58 (1.29–1.93)	2.16	1.80 (1.45–2.23)	1.74	1.54 (1.32–1.81)
Postnatal exposure[d]	1.0[c]	1.0[c]	1.26	1.18 (1.01–1.38)		

n = 12,068 with information about prenatal and postnatal exposure; n = 12,112 with information about prenatal exposure; n = 13,054 with information about postnatal exposure.
[a]OR for prenatal exposure adjusted for postnatal exposure.
[b]Adjusted for sex of child, age of mother, smoking during pregnancy, mother's psychiatric problems, and socio-occupational levels.
[c]Reference category.
[d]OR for postnatal exposure adjusted for prenatal exposure.

TABLE 3. Associations of Specific Behavioral Problems in Children With Prenatal and Postnatal Exposure to Cell Phone Use

	Prenatal Exposure Only		Postnatal Exposure Only		Both Prenatal and Postnatal Exposure	
	Unadjusted OR	Adjusted OR (95% CI)[a]	Unadjusted OR	Adjusted OR (95% CI)[a]	Unadjusted OR	Adjusted OR (95% CI)[a]
Behavioral problems						
Emotional	1.23	1.12 (0.97–1.30)	1.13	1.06 (0.92–1.23)	1.50	1.25 (1.07–1.47)
Hyperactivity	1.39	1.29 (1.08–1.53)	1.00	0.98 (0.82–1.17)	1.52	1.35 (1.12–1.63)
Conduct problems	1.29	1.21 (1.05–1.40)	1.06	1.02 (0.89–1.18)	1.69	1.49 (1.28–1.74)
Peer problems	1.36	1.27 (1.06–1.52)	1.11	1.08 (0.90–1.29)	1.51	1.34 (1.11–1.63)

Reference category is no prenatal or postnatal exposure to cell phone use.
[a]Adjusted for sex of child, age of mother, smoking during pregnancy, mother's psychiatric problems, and socio-occupational levels.

TABLE 4. Associations of Overall Behavioral Problems With Prenatal and Postnatal Exposure to Cell Phone Use Stratified by Covariates

Covariates	Prenatal Exposure Only OR (95% CI)	Postnatal Exposure Only OR (95% CI)	Both Prenatal and Postnatal Exposure OR (95% CI)
Sex of child			
Boy (n = 6201)	1.89 (1.48–2.40)	1.20 (0.92–1.58)	2.35 (1.81–3.06)
Girl (n = 5856)	1.55 (1.09–2.21)	1.44 (1.04–1.99)	2.12 (1.51–2.97)
Social-occupational level			
High level (n = 6259)	1.76 (1.27–2.46)	1.27 (0.90–1.79)	2.32 (1.63–3.30)
Medium level (n = 4359)	1.86 (1.39–2.51)	1.40 (1.04–1.89)	1.92 (1.40–2.64)
Low level (n = 1009)	1.22 (0.74–2.02)	0.67 (0.36–1.27)	1.56 (0.95–2.55)
Mother ever suffered from mental disorder or neurosis			
Yes (n = 710)	1.12 (0.56–2.27)	0.68 (0.33–1.42)	1.59 (0.84–3.01)
No (n = 10,937)	1.83 (1.48–2.26)	1.29 (1.03–1.60)	2.16 (1.72–2.69)
Mother ever had psychiatric illness			
Yes (n = 1424)	1.50 (0.96–2.3)	1.10 (0.71–1.69)	1.57 (1.02–2.41)
No (n = 10,349)	1.72 (1.36–2.17)	1.26 (0.99–1.60)	2.08 (1.62–2.66)
Mother's smoking status during pregnancy			
Smoked entire pregnancy (n = 2160)	1.75 (1.22–2.51)	0.89 (0.59–1.32)	1.71 (1.18–2.47)
Smoked early in pregnancy only (n = 822)	2.21 (0.99–4.96)	1.51 (0.68–3.37)	2.68 (1.24–5.80)
Not a smoker (n = 8378)	1.70 (1.31–2.20)	1.32 (1.01–3.37)	2.00 (1.50–2.66)

TABLE 5. Association of Characteristics of Mother's Cell Phone Use During Pregnancy With Overall Behavioral Problems Score in Children With Prenatal Exposure (n = 3322)

	No. (%)	Unadjusted OR	Adjusted OR (95% CI)[a]	Adjusted OR (95% CI)[a,b]
Times spoken per day				
0–1	1873 (56.4)	1.00[c]	1.00[c]	1.00[c]
2–3	777 (23.4)	1.49	1.33 (0.99–1.79)	1.31 (0.97–1.77)
4+	347 (10.4)	1.60	1.51 (1.02–2.22)	1.47 (1.00–2.18)
Missing	325 (9.8)	—	—	—
P for trend	—	0.28	0.61	0.62
Percentage of time turned on				
0	397 (12.0)	1.00[c]	1.00[c]	1.00[c]
<50	500 (15.1)	0.70	0.62 (0.35–1.11)	0.62 (0.35–1.10)
50–99	954 (28.7)	1.20	0.93 (0.58–1.48)	0.91 (0.57–1.45)
100	1427 (43.0)	1.43	1.09 (0.70–1.70)	1.06 (0.68–1.65)
Missing	44 (1.2)	—	—	—
P for trend	—	0.15	0.13	0.13

[a]Estimates adjusted for sex of child, age of mother, smoking during pregnancy, mother's psychiatric problems, and socio-occupational levels.
[b]Also adjusted for postnatal exposure to cell phones.
[c]Reference category.

proxies for intensity of mother's phone use during pregnancy did not exhibit strong dose-response associations, and tests for trend were not statistically significant.

DISCUSSION

Use of cell phones during pregnancy was associated with an increased odds of behavioral problems in children in this study. These results were unexpected and should be interpreted with caution. Observed associations are not necessarily causal. We have no known biologic mechanisms to explain these associations, and confounding by unmeasured causes of behavioral problems could have produced these results. Furthermore, this is the first study of its kind. The highest exposure group differed somewhat on several factors that might relate to the risk of behavioral disorders in offspring: they were of lower social-occupational status, mothers were more likely to

have ever suffered from mental disorder or neurosis and to ever had psychiatric illness, and mothers were more likely to have smoked during pregnancy. Although the associations remained after adjustment for these factors, and the associations were actually stronger in the covariate strata associated with lower risk of behavior disorders in offspring, the possibility of residual confounding remains. Additionally, we did not have information on other potential confounders such as history of psychiatric disorders in fathers and history of lead exposure.[28]

Another possible explanation for the observed association might be the lack of attention given to a child by mothers who are frequent users of cell phones. It is also possible that behavioral correlates of maternal cell phone use, rather than radiofrequency exposure, affect perception or reality of children's behavioral problems. Thus confounding and other sources of bias may explain the associations observed.

The validity of our measure of behavioral problems based on the questionnaire is supported by the fact that the prevalence of observed behavioral problems is consistent with results from similar studies in which the questionnaire has been used and validated.[29,30] Additionally, we observed associations in the expected direction and magnitude for other risk factors for behavioral problems, such as sex of the child, age of mother, social-occupational status, psychiatric history of mother and smoking during pregnancy.[20,21] We measured mother's reports of their children's behavioral traits or patterns rather than clinical diagnoses such as ADHD.

While the questionnaire was designed to obtain history of cell phone use, we do not believe that differential recall bias explains the observed associations. The portion of the questionnaire asking about behavioral problems preceded the questions regarding cell phone use, but it is unlikely that mothers would be influenced by the knowledge of their child's behavioral status when providing data of phone use, as these behavioral problems have not previously been associated with cell phone use. A previous study has shown good accuracy for the simple reporting of use versus nonuse of cell phones, and reasonable reporting (underreporting of 10%) for times spoken per day.[31] Self-reported duration of calls was more problematic, being overestimated by 40%.

Because pregnancy leaves a strong impression on memory—allowing for mothers to recall events fairly well and actions during that time—we expect recall related to a specific pregnancy to provide better data than recall without such a stimulus, and a number of studies have supported this view.[32–35] Thus our estimates of exposure, which are based on cell phone use and number of calls, may be better than for the case-control studies of brain tumors published to date, although we do not expect the data to be without error.

Obtaining actual exposure dose measurements to radiofrequency fields in a large prospective cohort is unrealistic. Basing exposure data as collected by a well-designed questionnaire is the only practical way of obtaining cell phone use information for children in a large cohort study. It would be useful to know how well reported use of cell phone by mothers approximates exposure to the fetus. Adequate models estimating the specific absorption rate to a fetus from cell phones are still under development.[36] Based on the distance from outside the body to inside the uterus, the exposure reaching the fetus (either during conversation or when the phone is in a standby mode) is likely to be extremely low. Although unlikely, thermal effects due to localized increases in temperature should be considered, given that the temperature of the fetus is already about 0.5°C above that of the mother[37] and fetal heat dissipation to the mother (which occurs mostly at the placenta) is not fully efficient.

The specific absorption rate for children is somewhat higher than for adults due to differences in body size, shape, tissue distribution, as well as permittivity and conductivity of tissues. In addition, the relative penetration is deeper for children, a logical consequence of the smaller head diameter. Nevertheless, use of cell phones by children in this group was so infrequent and short term that the casual effect due to these exposures seems unlikely, according to our present knowledge.

About 30% of 7-year-olds used cell phones in Denmark, albeit infrequently. Although the difference in cell phone use by mothers and children between the 2 years of enrollment (1998 and 1999) was small, prevalence of use was increasing and will likely increase further as the children age. Many families will probably not have land-lines in the future, thus increasing frequency of cell phone use even more. In a recent Swedish study, nearly half of 7-year-olds had access to cell phones and prevalence increased sharply with age, to 98% of 14-year-olds.[38]

The immature nervous system is extremely vulnerable to toxicants, which can result in behavior-related toxicities that may not emerge until well into childhood, adolescence or adulthood.[39,40] Thus it will be useful to continue to follow this cohort of children.

Examination of the possible effect of prenatal and postnatal cell phone exposure on cognitive development and behavior is best done in a longitudinal study. Our results need to be replicated; they only suggest that cell phone use during critical periods of brain development in pregnancy and early childhood could be a potential risk factor for behavioral problems in children. We hope others will be able to pursue this question in other cohorts of children. The observed associations may be noncausal and due to unmeasured confounding; however, if they are real they would have major public health implications.

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