JECH Online First, published on December 7, 2010 as 10.1136/jech.2010.115402



Cell phone use and behavioural problems in young children

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Accepted 22 September 2010

ABSTRACT

Background Potential health effects of cell phone use in children have not been adequately examined. As children are using cell phones at earlier ages, research among this group has been identified as the highest priority by both national and international organisations. The authors previously reported results from the Danish National Birth Cohort (DNBC), which looked at prenatal and postnatal exposure to cell phone use and behavioural problems at age 7 years. Exposure to cell phones prenatally, and to a lesser degree postnatally, was associated with more behavioural difficulties. The original analysis included nearly 13 000 children who reached age 7 years by November 2006.

Methods To see if a larger, separate group of DNBC children would produce similar results after considering additional confounders, children of mothers who might better represent current users of cell phones were analysed. This 'new' dataset consisted of 28 745 children with completed Age-7 Questionnaires to December 2008.

Results The highest OR for behavioural problems were for children who had both prenatal and postnatal exposure to cell phones compared with children not exposed during either time period. The adjusted effect estimate was 1.5 (95% CI 1.4 to 1.7).

Conclusions The findings of the previous publication were replicated in this separate group of participants demonstrating that cell phone use was associated with behavioural problems at age 7 years in children, and this association was not limited to early users of the technology. Although weaker in the new dataset, even with further control for an extended set of potential confounders, the associations remained.

Technological developments now bring social and economic benefits to large sections of society; however, the health consequences of these developments can be difficult to predict. Sources of radio frequency electromagnetic fields (EMF) have been present as a result of radio and TV broadcasts since the early 20th century. EMF from radar and related technologies has been present since the mid-20th century. EMF from cellular communications has come along in the last quarter of the previous century, and in just the past few years, sources of EMF from Wi-Fi, RFID and other novel technologies have come into existence. All these sources have increased considerably since first emerging, and increases in cellular communications and other radio frequency technologies in the past decade have been particularly rapid. The worldwide proportion subscribing to cell phones has increased from 5% approximately 15 years ago to well over 70% who are current users.[1] If cell phones lead to adverse health effects associated with their use, then the potential rise in health burden could be significant.

Exposure to cell phones is increasingly becoming prevalent among children at younger ages. Also of concern is use by expectant mothers. Previously, we reported an association from the Danish National Birth Cohort (DNBC) for prenatal and postnatal exposure to cell phone use and behavioural problems at age 7 years among nearly 13 000 Danish children born between 1997 and 1999.[2]

In order to determine whether our original results were a chance finding, or because the initial sample were 'early adopters of technology' who are more likely to have behavioural problems and whose children are likely to have similar behavioural patterns, we analysed a new and separate group of mothers and children from the DNBC. Compared with our previous efforts we further adjusted for an extended set of potential confounders, including variables that reflect mother's attention towards the child early in life.

METHODS

From March 1996 to November 2002, the DNBC recruited nearly 100 000 pregnant mothers with the intent to follow these women and their offspring longitudinally in a life-course perspective.[3 4] Mothers reported detailed information on lifestyle factors, dietary habits and environmental exposures collected by means of four telephone interviews—two during pregnancy and two within 18 months postpartum.[5] With the resources of the various administrative, health and socioeconomic registers, information was linkable for cohort participants by means of a 'central person register' number that is assigned to all Danish persons.[6] In this analysis, information from the Danish Medical Birth Registry was linked with DNBC data.[7]

When offspring reached 7 years of age, a new questionnaire was administered to mothers on information pertaining to the health of her child. Questions on cell phone use among children, as well as among mothers during pregnancy, were asked. More detailed prenatal cell phone use information included: historical use of cell phone by mother (year of first regular use, amount of use during pregnancy); use of hands-free equipment by mother (proportion of time); use of hands-free equipment during pregnancy and location of the phone (handbag or pant/shirt/jacket pocket) and current use of cell phones.

The Age-7 Questionnaire also included data on social conditions, family lifestyle and diseases in childhood, including behavioural problems as defined by the strengths and difficulties questionnaire (SDQ).[8 9] Mothers completed a list of 25

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questions with scaled responses (very true, partly true, or not true) regarding their child's behaviour. Scores were summed over a particular group of questions assessing for overall and specific behavioural problems or disorders with a priori defined cut-off points. Based on the score, children were classified as normal (0–13), borderline (14–16), or abnormal (17–40) for having 'overall behavioural problems'.

Our analysis included comparisons between covariates (potential confounders) and prenatal and postnatal cell phone exposure. Covariates of interest included: child's gender; mother's age at birth; father's age at birth; mother's history of psychiatric problems (self-reported from Age-7 Questionnaire); mother's history of psychiatric, behavioural, or cognitive problems as child (self-reported from prenatal interviews); father's history of psychiatric, behavioural, or cognitive problems as child (spousal report from prenatal interviews); social occupational status; prenatal smoking (entire pregnancy, early pregnancy, or not a smoker); prenatal alcohol (entire, early, or late pregnancy only, or not at all) and prenatal marijuana use (yes or no); prenatal stress (14-point summary score categorised as low (0–4), medium (5), high (6–14)); prenatal physical activity (entire, early, or late pregnancy, or no activity); other sources of prenatal ionising and non-ionising radiation (ie, x-rays, ultrasound); parity; gestational age; birth weight; postpartum stress (15-point summary score categorised as low (0–3), medium (4), high (5–15)); child breastfed for at least the first 6 months (yes or no); hours spent with child daily by age 6 and 18 months; and child in daycare by 18 months.

An ordinal logistic regression model was used to estimate the odds of the overall behavioural problems (0, normal; 1, borderline; 2, abnormal) according to prenatal and postnatal exposure to cell phones. Regression models were adjusted for covariates from the original analysis such as child's gender, mother's age at birth, mother's social occupational status, prenatal smoking, and mother's history of psychiatric problems. Regression modelling also considered covariates not included in the previous publication such as both parents' history of psychiatric, cognitive, or behavioural problems as a child, a combined social occupational status, prenatal alcohol and drug use, prenatal physical activity, other prenatal radiation sources, father's age at birth, gestational age, parity, birth weight, postpartum stress, breast feeding, hours spent daily by ages 6 and 18 months, and child in daycare by 18 months. Certain covariates (risk factors) were not associated with the outcome of interest in this analysis and were eliminated. Also certain covariates were not associated with exposure and were found not to be statistically significant ($p > 0.05$) in a multivariate model that included the exposure and outcome. The log likelihood ratio test was utilised during the model building process to develop a parsimonious model by manually eliminating variables at a p value greater than 0.05.

Proxies of prenatal exposure intensity (times per day spoken, location of the phone when not used, proportion of time the phone was turned on, and use of an earpiece with cell phone) were used to evaluate possible dose–response patterns. Depending on the characteristic, 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'.

Previously, we reported data for 13 159 Danish children born between 1997 and 1999.[2] In this analysis, a 'new' and separate dataset of Danish children (born 1998–2002) was utilised. For comparison, results from 12 796 of the 'original' children were included after excluding 363 'original' children who were born as part of a set of twins or triplets. This analysis for comparability purposes includes singleton, live births in both datasets: 'original' and 'new', and concludes with an analysis of the 'combined' datasets.

Human ethics review approvals were obtained from the Danish Data Protection Agency (Datatilsynet) and the University of California, Los Angeles (UCLA) Office for the Protection of Research Subjects.

RESULTS

Results are presented for the 'original' (n=12 796) and 'new' (n=28 745) datasets for all DNBC singleton, live births followed up to age 7 years. In both datasets 30.5% (original) and 35.2% (new) of children, were using a cell phone at the age of 7 years, but less than 1% used a cell phone for more than 1 h per week in both datasets. In the original dataset, 10.1% of children had both prenatal and postnatal (joint) exposure, whereas among the new dataset of children, 17.9% were jointly exposed. Respectively, 53.3% and 39.5% of children in the original and new datasets

Table 1 Association of prenatal and postnatal exposure to cell phone use with overall behavioural problems by type of dataset and by birth year

	Original dataset			New dataset		
	OR	aOR†	95% CI	OR	aOR†	95% CI
All birth years*						
n	12 796‡			28 745§		
Prenatal and postnatal exposure	2.2	1.9	1.5 to 2.3	1.9	1.5	1.3 to 1.7
Prenatal exposure only	1.7	1.5	1.3 to 1.9	1.5	1.3	1.1 to 1.5
Postnatal exposure only	1.2	1.2	1.0 to 1.4	1.2	1.2	1.0 to 1.4
No exposure	1.0	1.0	–	1.0	1.0	–
1998						
n	5685‡			1090§		
Prenatal and postnatal exposure	2.4	2.0	1.5 to 2.8	3.4	3.4	1.5 to 7.9
Prenatal exposure only	1.4	1.2	0.8 to 1.7	1.7	1.5	0.6 to 3.8
Postnatal exposure only	1.2	1.1	0.8 to 1.4	2.0	2.1	1.0 to 4.4
No exposure	1.0	1.0	–	1.0	1.0	–
1999						
n	7076‡			4214§		
Prenatal and postnatal exposure	2.1	1.8	1.3 to 2.4	2.2	1.9	1.4 to 2.7
Prenatal exposure only	2.0	1.8	1.3 to 2.4	1.5	1.4	1.0 to 1.9
Postnatal exposure only	1.3	1.2	1.0 to 1.6	1.3	1.2	0.9 to 1.7
No exposure	1.0	1.0	–	1.0	1.0	–
2000						
n	–			13 115§		
Prenatal and postnatal exposure	–	–	–	1.9	1.4	1.1 to 1.7
Prenatal exposure only	–	–	–	1.5	1.3	1.0 to 1.6
Postnatal exposure only	–	–	–	1.2	1.2	0.9 to 1.5
No exposure	–	–	–	1.0	1.0	–
2001						
n	–			9682§		
Prenatal and postnatal exposure	–	–	–	1.8	1.4	1.1 to 1.8
Prenatal exposure only	–	–	–	1.5	1.3	1.1 to 1.7
Postnatal exposure only	–	–	–	1.0	1.0	0.7 to 1.4
No exposure	–	–	–	1.0	1.0	–

*Includes the years 1997 (n=24) and/or 2002 (n=635).
†Adjusted for sex of child, mother's age at birth, mother's socio-occupational status, smoking during pregnancy, and mother's psychiatric history.
‡Singleton, live births; our previous analysis included 13 159 children of singleton and multiple, live births; 363 children of multiple births were not included in this analysis.
§Singleton, live births.
aOR, adjusted odds ratio.

had neither prenatal nor postnatal cell phone use exposure. Tests for trend indicated that patterns of cell phone use did change with birth year for both datasets.

Regarding overall behavioural problems, 93.5% (original) and 93.0% (new) of children had no recorded behavioural problems. In both 3.3% were considered borderline and 2.9% (original) and 3.1% (new) of children scored as abnormal.

In table 1, the joint exposures were positively associated with overall behavioural problems. These estimates for both datasets were adjusted for the original set of covariates as previously published.[2] The highest OR for behavioural problems were observed for children who had a joint exposure compared with no exposure. Adjusting for potential confounders moved the results towards the null. In the new dataset, the joint exposure association with overall behavioural problems by birth year decreased from 1998 to 2001 yet remained incompatible with the null. Unadjusted and adjusted models with an interaction term (cell phone use and birth year) were tested and found not to be statistically significant at the p=0.05 level (not shown).

Figure 1 shows the association between certain adjusted covariates and the joint exposure to cell phone use for both datasets. Children with prenatal and postnatal exposures were more often in the lower social occupational status, to have mothers who smoked during pregnancy, to have younger mothers and to have mothers with higher prenatal stress scores. The percentage of parents for whom childhood history of psychiatric, cognitive, or behavioural problems was unknown was higher among the 'original' dataset (early adopters of cell phone technology).

Supplementary tables A1 and A2 (available online only) present all of the covariates considered in this analysis by levels of exposure (no cell phone exposure, prenatal exposure only, postnatal exposure only, or joint exposure) for both datasets. Worth noting are the greater number children whose mothers

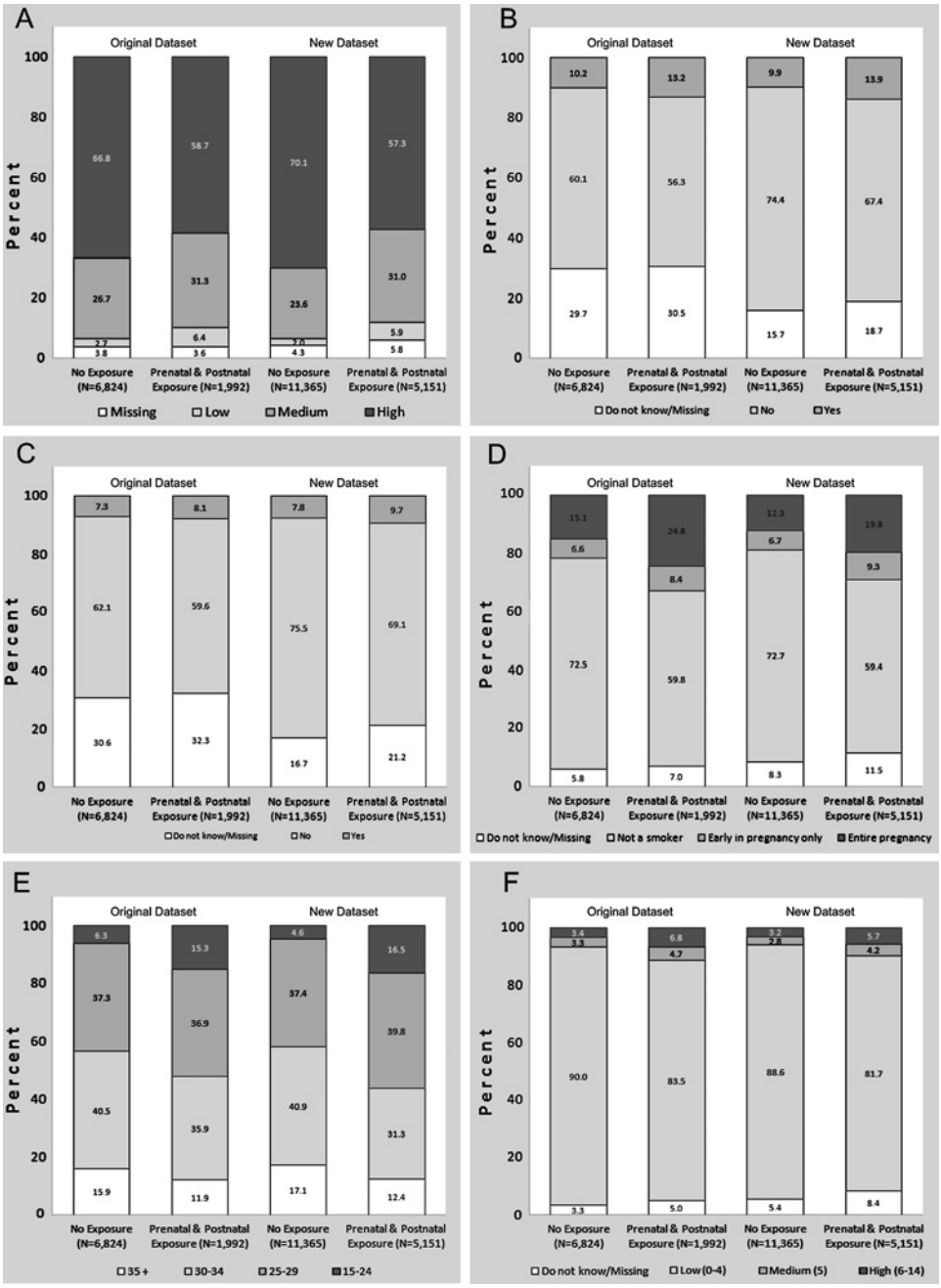


Figure 1 Prenatal and postnatal (joint) exposure to cell phone use by type of dataset and percentage distributions for selected covariates: parents' combined social ccupational status (A); mother's history of psychiatric, cognitive or behavioural problems as a child (B); father's history of psychiatric, cognitive or behavioural problems as a child (C); mother's smoking status during pregnancy (D); mother's age at child's birth (E); and mother's stress score during pregnancy (F).

reported 'not smoking' during pregnancy with no cell phone exposure or with prenatal exposure only compared with children with postnatal only or joint exposure in both datasets. Another difference is the greater percentage of children at birth with mothers 15–24 years of age with joint exposure compared with prenatal only, postnatal only, or no exposure in both datasets.

Table 2 presents estimates for the 'combined' dataset ('original' and 'new', n=41 541). The adjusted OR in the 'combined' dataset for overall behavioural problems score was 1.6 for the joint exposure. Upon further adjustment, the OR for prenatal and postnatal exposure was 1.5 (95% CI 1.4 to 1.7). This final model was adjusted for sex of child, mother's age at birth, mother's and father's history of psychiatric, cognitive or behavioural problems as a child, combined socio-occupational status, gestational age, mother's prenatal stress, and child breastfed up to 6 months of age. For prenatal or postnatal exposure only, the adjusted OR were 1.4 (95% CI 1.2 to 1.5) and 1.2 (95% CI 1.0 to 1.3), respectively.

When analyses were stratified by the modelled covariates, the associations between cell phone use and overall behavioural problems remained across the strata (table 3). These results demonstrate that the selected covariates confound the association between cell phone use and behavioural problems if not controlled, yet complete confounder control is unlikely due to residual confounding caused by measurement error for these covariates. For nearly all strata of covariates, the highest OR were for those with the joint exposure.

Table 2 Association of prenatal and postnatal exposure to cell phone use with overall behavioural problems by birth year among all children (combined dataset, n=41 541)

	OR	aOR†	95% CI	OR‡	95% CI
All birth years* (n=41 541)					
Prenatal and postnatal exposure	2.0	1.6	1.4 to 1.8	1.5	1.4 to 1.7
Prenatal exposure only	1.5	1.4	1.2 to 1.5	1.4	1.2 to 1.5
Postnatal exposure only	1.2	1.2	1.0 to 1.3	1.2	1.0 to 1.3
No exposure	1.0	1.0	—	1.0	—
1998 (n=6775)					
Prenatal and postnatal exposure	2.5	2.2	1.6 to 3.0	2.2	1.7 to 3.0
Prenatal exposure only	1.4	1.2	0.9 to 1.7	1.3	1.0 to 1.8
Postnatal exposure only	1.3	1.2	0.9 to 1.6	1.3	1.0 to 1.7
No exposure	1.0	1.0	—	1.0	—
1999 (n=11 290)					
Prenatal and postnatal exposure	2.2	1.9	1.5 to 2.3	1.8	1.5 to 2.3
Prenatal exposure only	1.8	1.6	1.3 to 2.0	1.5	1.3 to 1.9
Postnatal exposure only	1.3	1.2	1.0 to 1.5	1.2	1.0 to 1.5
No exposure	1.0	1.0	—	1.0	—
2000 (n=13 115)					
Prenatal and postnatal exposure	1.9	1.4	1.1 to 1.7	1.3	1.1 to 1.6
Prenatal exposure only	1.5	1.3	1.0 to 1.6	1.2	1.0 to 1.5
Postnatal exposure only	1.2	1.2	0.9 to 1.5	1.2	1.0 to 1.5
No exposure	1.0	1.0	—	1.0	—
2001 (n=9682)					
Prenatal and postnatal exposure	1.8	1.4	1.1 to 1.8	1.4	1.1 to 1.7
Prenatal exposure only	1.5	1.4	1.1 to 1.7	1.4	1.1 to 1.7
Postnatal exposure only	1.0	1.0	0.7 to 1.4	1.0	0.8 to 1.4
No exposure	1.0	1.0	—	1.0	—

*Includes the years 1997 (n=24) and/or 2002 (n=635).
†Adjusted for sex of child, mother's age at birth, mother's socio-occupational status, smoking during pregnancy, and mother's psychiatric history.
‡Adjusted for sex of child, mother's age at birth, mother's and father's history of psychiatric, cognitive or behavioural problems as a child, combined socio-occupational status, gestational age, mother's prenatal stress, and child breastfed up to 6 months of age.
aOR, adjusted odds ratio.

Table 3 Association of overall behavioural problems with prenatal and postnatal exposure to cell phone use stratified by covariates

	Prenatal and postnatal exposure OR (95% CI)	Prenatal exposure only OR (95% CI)	Postnatal exposure only OR (95% CI)
Social occupational status (combined)			
High level (n=27170)	1.6 (1.4 to 1.9)	1.2 (1.0 to 1.4)	1.1 (0.9 to 1.3)
Medium level (n=11 185)	2.1 (1.7 to 2.5)	1.9 (1.6 to 2.3)	1.4 (1.2 to 1.7)
Low level (n=1374)	1.8 (1.2 to 2.6)	2.2 (1.5 to 3.4)	1.2 (0.7 to 1.9)
Sex of child			
Boy (n=21 284)	2.1 (1.9 to 2.4)	1.6 (1.4 to 1.8)	1.3 (1.1 to 1.5)
Girl (n=20 237)	1.9 (1.6 to 2.3)	1.4 (1.1 to 1.6)	1.3 (1.1 to 1.6)
Mother's history of psychiatric, cognitive, or behavioural problems as a child			
Yes (n=4579)	2.4 (1.9 to 3.1)	1.7 (1.3 to 2.2)	1.2 (0.8 to 1.5)
No (n=28 411)	1.7 (1.4 to 1.9)	1.5 (1.3 to 1.7)	1.1 (1.0 to 1.3)
Father's history of psychiatric, cognitive, or behavioural problems as a child			
Yes (n=3378)	2.2 (1.6 to 2.9)	2.1 (1.5 to 2.9)	1.0 (0.7 to 1.5)
No (n=29 034)	1.8 (1.6 to 2.0)	1.4 (1.2 to 1.6)	1.2 (1.0 to 1.3)
Mother's age at child's birth (years)			
15–24 (n=3453)	1.8 (1.4 to 2.3)	1.6 (1.2 to 2.1)	0.8 (0.6 to 1.2)
25–29 (n=15 868)	1.7 (1.4 to 2.0)	1.5 (1.2 to 1.7)	1.2 (1.0 to 1.4)
30–34 (n=15 904)	1.7 (1.4 to 2.1)	1.3 (1.1 to 1.7)	1.2 (1.0 to 1.5)
35–39 (n=5625)	1.7 (1.2 to 2.4)	1.2 (0.8 to 1.7)	1.6 (1.2 to 2.3)
40 or older (n=691)	1.2 (0.3 to 4.5)	2.6 (1.1 to 6.4)	1.4 (0.5 to 4.2)
Gestational age at birth (weeks)			
<37 (n=1979)	2.1 (1.4 to 3.1)	2.1 (1.4 to 3.2)	1.2 (0.8 to 1.9)
37–41 (n=35 686)	1.9 (1.7 to 2.1)	1.5 (1.3 to 1.7)	1.0 (0.5 to 1.7)
42 or greater (n=3769)	2.2 (1.6 to 3.1)	1.4 (1.0 to 2.0)	1.2 (1.1 to 1.4)
Mother's stress score during pregnancy			
Low (0–4) (n=36 085)	1.8 (1.6 to 2.0)	1.4 (1.3 to 1.6)	1.2 (1.1 to 1.4)
Medium (5) (n=1430)	2.2 (1.4 to 3.4)	1.6 (1.0 to 2.6)	1.0 (0.5 to 1.7)
High (6–14) (n=1693)	2.9 (2.0 to 4.2)	2.5 (1.6 to 3.8)	1.2 (0.8 to 1.9)
Child breastfed for at least the first 6 months			
Yes (n=25 066)	1.7 (1.5 to 2.0)	1.5 (1.3 to 1.7)	1.3 (1.1 to 1.5)
No (n=7629)	1.8 (1.4 to 2.1)	1.4 (1.1 to 1.7)	0.9 (0.7 to 1.1)

To estimate mother's inattention we looked at variables such as breastfeeding up to 6 months of age, reported number of hours spent with child at ages 6 and 18 months, and whether child was in regular daycare by 18 months of age. In table 4, the only covariates that were associated with overall behavioural problems were breastfeeding up to 6 months of age and spending less time daily with the child at 6 months.

In the combined dataset, considering prenatal cell phone use characteristics (independent of postnatal use by child), almost 85% of mothers carried their cell phone in a bag during pregnancy rather than on their person or elsewhere, and nearly 80% reported not using an earpiece (not shown). In table 5, more than 10% of children with prenatal exposure had mothers who reported speaking four times per day or more during their pregnancy and 48.5% reported having the phone turned on at all times. For prenatal exposures, regardless of control for postnatal

Table 4 Association of proxy covariates for mother's inattention with overall behavioural problems in children

	Original dataset (n=12 796)		New dataset (n=28 745)		Combined dataset (n=41 541)	
	OR	95% CI	OR	95% CI	OR	95% CI
Child breastfed for at least the first 6 months						
Yes	0.6	0.5 to 0.7	0.5	0.5 to 0.6	0.5	0.5 to 0.6
No	1.0	—	1.0	—	1.0	—
Reported amount of hours spent per day with child at age 6 months interview						
<1	1.5	1.1 to 2.0	1.5	1.2 to 1.9	1.5	1.2 to 1.8
1—7	1.1	0.9 to 1.4	1.3	1.1 to 1.5	1.2	1.1 to 1.4
8 or more	1.0	—	1.0	—	1.0	—
Reported amount of hours spent per day with child at age 18 months interview						
<1	1.1	0.9 to 1.4	0.9	0.8 to 1.1	1.0	0.9 to 1.1
1—4	1.1	0.8 to 1.5	1.2	1.0 to 1.4	1.2	1.0 to 1.3
5	1.0	0.8 to 1.3	0.9	0.8 to 1.1	1.0	0.8 to 1.1
6—7	1.0	0.8 to 1.3	0.8	0.6 to 0.9	0.8	0.7 to 1.0
8 or more	1.0	—	1.0	—	1.0	—
Child in regular daycare outside the home at age 18 months interview						
Yes	1.1	0.8 to 1.4	0.9	0.8 to 1.1	1.0	0.8 to 1.1
No	1.0	—	1.0	—	1.0	—

exposure, adjusted OR for the overall behavioural problems score tended to be greater with higher potential for fetal exposure. Proxies for intensity of mother's phone use during pregnancy did exhibit dose—response associations, and tests for trend were statistically significant.

DISCUSSION

Using a new group of participants from the DNBC, we replicated our previously reported study on prenatal and postnatal (joint) exposure to cell phones. Our results make it unlikely that the first finding was by chance, but our estimate was higher in the 'original' dataset (adjusted OR 1.9) compared with the 'new' dataset (adjusted OR 1.5).

Table 5 Association of characteristics of mother's cell phone use during pregnancy with overall behavioural problems score in children with prenatal exposure (n=13 938)

	No. (%)	OR	aOR* (95% CI)	aOR† (95% CI)
Times spoken daily				
0—1	7268 (52.2)	1.0	1.0	1.0
2—3	3703 (26.6)	1.4	1.2 (1.0 to 1.4)	1.2 (1.0 to 1.4)
4+	1409 (10.8)	1.7	1.4 (1.2 to 1.7)	1.4 (1.2 to 1.7)
Missing	1458 (10.4)	—	—	—
p for trend	—	0.09	0.07	0.07
Percentage of time turned on (%)				
0	1098 (7.9)	1.0	1.0	1.0
<50	1788 (12.8)	1.6	1.4 (1.0 to 2.1)	1.4 (1.0 to 2.1)
50—99	4201 (30.1)	2.2	1.7 (1.2 to 2.3)	1.7 (1.2 to 2.3)
100	6750 (48.5)	2.8	2.0 (1.4 to 2.7)	2.0 (1.4 to 2.7)
Missing	101 (0.7)	—	—	—
p for trend	—	<0.0001	0.003	0.004

*Adjusted for sex of child, mother's age at birth, mother's and father's history of psychiatric, cognitive or behavioural problems as a child, combined socio-occupational status, gestational age, mother's prenatal stress and child breastfed up to 6 months of age.
†Adjusted for sex of child, mother's age at birth, mother's and father's history of psychiatric, cognitive or behavioral problems as a child, combined socio-occupational status, gestational age, mother's prenatal stress, child breastfed up to 6 months of age and postnatal exposure to cell phones.
aOR, adjusted odds ratio.

Many including ourselves have raised concerns regarding the role of uncontrolled confounding as well as unmeasured confounding in the original analysis.[10] Here, we examined numerous other covariates that were not considered previously. With the addition of these variables, the association still remained. Although we took a larger set of potential confounders into consideration there was no appreciable effect on the results.

We also hypothesised that greater cell phone use during pregnancy may be indicative of mother's inattention in rearing her child, thus providing an alternative explanation for the positive association with behavioural problems in children. As this study was not designed to observe direct mother—child interactions or how much attention a mother gave her child, we used measures of breastfeeding and hours spent per day as proxy measures for this covariate. Breastfeeding was inversely associated (OR 0.5 in the combined dataset) with overall behavioural problems but did not diminish the association between cell phone exposure and the outcome when included. If breastfeeding and time spent with child are good measures of mothers' attention then we believe that our results do not support inattention as a likely explanation for the observed association.

It has been suggested that our initial results were due to characteristics of early technology adopters of cell phones and that these parents' behaviour may strongly influence and predict overall behavioural problems in their children. These findings are not limited to a unique group of parents in the early part of our cohort, but are replicated in a more general population of Danish mothers who used cell phones during pregnancy.

There were concerns that the SDQ as an instrument might be too non-specific and biased if mothers have children with other serious mental and health conditions before SDQ administration. However, our work and the work of others indicates both the internal validity of SDQ and its ability to predict clinical diagnosis for overall behavioural problems.[8 9 11]

We also do not believe that differential recall bias explains the observed associations. We have tested this exposure assessment method with other outcomes and did not find an association (data not shown). It is highly unlikely that reporting prenatal or postnatal cell phone use would be influenced by the mother's knowledge or suspicion of her child's behavioural status and not by more debilitating neurological outcomes such child's history of febrile seizures or epilepsy, which we looked at.

Modelling specific absorption rates (SAR) of radiofrequency fields to the womb of pregnant mothers suggest that exposures are likely to be low and not high enough to elevate the body temperature,[12—14] but modelling is based on numerous assumptions and extrapolations. In addition, possible non-thermal effects of radiofrequency fields remain of interest. In a recent letter to the editor, Hocking[15] cites a review article by Brzezinski[16] that suggests talking on a cell phone—placed on the side of the head by the ear and jaw—may lead to increased melatonin secretion due to the excitation of nearby post-ganglionic nerves that lead to the pineal gland, which is responsible for producing melatonin. One of the many things that this hormone does is to inhibit the secretion of gonadotropin-releasing hormone thus directly affecting steroid metabolism within the ovaries and progesterone synthesis. It is believed that diverse changes in maternal metabolism or the sex hormone environment can affect the development of the fetal brain thus leading to behavioural problems.[15]

Vrijheid *et al*[17] recently published results reporting no association between prenatal exposure to cell phone use and neurodevelopment at 14 months among a smaller pregnancy

What is already known on this subject

Previous studies of cell phone use have emphasised health effects in adults. Yet the most susceptible population to environmental exposures are children. This past decade has seen a great increase worldwide in cell phone use and access. During this same period, an equally important public health outcome that has increased in prevalence is childhood behavioural problems.

What this study adds

There is an association between prenatal as well as postnatal use and behavioural problems by age 7 years among a general population of mothers who are cell phone users. These results replicate the findings of an association observed among only early technology adopters. These new results also reduce the likelihood that these are chance findings or findings that did not adequately consider the influence of other important factors for behavioural problems. These results should not be interpreted as demonstrating a causal link between cell phone use and adverse health effects for children, but if real—and given the nearly universal use of cell phones—the impact on the publics' health could be of concern.

cohort. Their findings point to the possibility that exposure may have specificity for a particular outcome such as behavioural problems, which probably has a different causal pathway than infant neurodevelopment delays.

Whereas it is unlikely that mothers would erroneously recall using or not using a cell phone, more detailed information such as trimester of use was difficult to recall. We assume that reported use correlates with levels of radiofrequency field exposure, which are truly unknown, and prenatal exposure is dichotomised, whereas the true exposure is a continuous value.

Data from the Age-7 Questionnaire represents nearly 60–65% of mothers and children eligible to participate. This is down from 80% participation for the 6 and 18 month interviews. In this research a proportional odds model for an ordinal logistic regression was utilised to understand behavioural problems. If the proportional odds assumption was truly incorrect, then model misspecification bias would have been introduced. This can be explored further through multinomial logit analyses in which such an assumption is not necessary.

Although it is premature to interpret these results as causal, we are concerned that early exposure to cell phones could carry a risk, which, if real, would be of public health concern given the widespread use of this technology. Even with limited scientific investigations into this research hypothesis, given that exposures to children and fetuses are easily reduced at virtually no cost, precautionary measures might be warranted. It is our hope that other scientists will attempt to replicate or refute the findings of our research based upon similar study designs. Also, prospective and detailed ascertainment would greatly improve exposure measurement quality. A random subsample, who are offered clinical evaluation for behavioural problems, would be another enhancement. Adequate populations of both exposed and unexposed are needed, but as cell phone technology is widely used, researchers will find it difficult to enrol these shrinking, unexposed populations.

Acknowledgements The authors would like to thank the coordinator of the data collection, Inge Kristine Meder, data analysts, Inge Eisensee and Lone Fredslund Møller, and the participating mothers.

Funding The Age-7 Questionnaire was financially supported by the Lundbeck Foundation (195/04) and the Danish Medical Research Council (SSVF 0646). Support for this work was provided by the UCLA School of Public Health, research innovation seed grant (4565963LK19914) and by an NIH/NIEHS grant (R21ES016831).

Competing interests None.

Ethics approval This study was conducted with the approval of the Danish Data Protection Agency (Datatilsynet) and the UCLA Office for the Protection of Research Subjects.

Provenance and peer review Not commissioned; externally peer reviewed.

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