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Prenatal cell phone use and developmental milestone delays among infants

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Objective The aim of this study was to examine if prenatal use of cell phones by pregnant mothers is associated with developmental milestones delays among offspring up to 18 months of age.

Methods Our work is based upon the Danish National Birth Cohort (DNBC), which recruited pregnant mothers from 1996–2002, and was initiated to collect a variety of detailed information regarding in utero exposures and various health outcomes. At the end of 2008, over 41 000 singleton, live births had been followed with the Age-7 questionnaire, which collected cell-phone-use exposure for mothers during pregnancy. Outcomes for developmental milestones were obtained from telephone interviews completed by mothers at age 6- and 18-months postpartum.

Results A logistic regression model estimated the odds ratios (OR) for developmental milestone delays, adjusted for potential confounders. Less than 5% of children at age 6 and 18 months had cognitive/language or motor developmental delays. At 6 months, the adjusted OR was 0.8 [95% confidence interval (95% CI) 0.7–1.0] for cognitive/language delay and 0.9 (95% CI 0.8–1.1) for motor development delay. At 18 months, the adjusted OR were 1.1 (95% CI 0.9–1.3) and 0.9 (95% CI 0.8–1.0) for cognitive/language and motor development delay, respectively.

Conclusions No evidence of an association between prenatal cell phone use and motor or cognitive/language developmental delays among infants at 6 and 18 months of age was observed. Even when considering dose–response associations for cell phone use, associations were null.

Key terms cellular phone; child development; mobile phone; mother; offspring; pregnancy.

Only a decade ago, approximately 5% of the worldwide population used cell phones as a regular tool for communication. Nowadays both access and use of cell phones has become nearly universal with the developing world seeing the greatest increase in use per individual in this time period (1). By the end of 2010, there were an estimated 5 billion cell phone subscribers worldwide (2).

During this time of rapid technological growth, the potential adverse health effects from cell phones have become a contentious topic debated among the scientific community as well as the general public. Early studies have focused on the use of cell phones and the risks for brain or other cancers of the head (3–5). Recently, the International Agency for Research on Cancer categorized radiofrequency electromagnetic fields, such as those associated with cell phones, as a possible carcinogen to humans based upon epidemiological studies of gliomas, which are one form of brain cancer (6). Numerous other health outcomes besides cancers are yet to be comprehensively evaluated. Previously, we reported findings that exposure to cell phone use prenatally as well as postnatally was associated with emotional and hyperactivity-like behavior among children by the age of seven (7). A subsequent analysis reported the same findings and considered the influence of other important factors for behavioral problems (8). We concluded that while it is still premature to consider these associations as causal, the public health implications for pregnant mothers and children are large if these associations are real.

For many environmental health exposures (such as lead, ionizing radiation, or particulate matter), children are more susceptible and succumb to greater adverse

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health outcomes compared to adults exposed to similar levels. The same may be true for radiofrequency fields (RF) (9). RF exposure at high levels may lead to heating resulting in thermal effects specifically on the neurological development of the fetus and continued neurological growth of the newborn child. Research modeling of specific absorption rates for RF from cell phones to the womb of pregnant mothers suggests that exposure is low and not high enough to elevate the body temperature (thermal effect) (10, 11). Recently, in a controlled experiment with healthy participants, researchers with the US National Institutes of Health reported observing increased brain glucose metabolism in the region closest to the cell phone antenna when the device was in operation. If confirmed by other studies, this would imply that there may be a biological, non-thermal effect from cell phones (12). Institutions such as the World Health Organization and the National Academy of Sciences have specifically advocated for increased research efforts into the possible health effects from cell phones and other new sources of exposure to radiofrequency fields especially for children and fetuses (13, 14).

In the first year of an infant's life, the brain doubles in physical size. While the number of neurons is thought to remain the same throughout our lives, changes occur to the synaptic connections over time. It is estimated that there are over 1 trillion new connections formed during infancy and childhood (15). These connections are mediated via various biological processes such as neurogenesis, axonal and dendritic growth, synaptogenesis, cell death, synaptic pruning, myelination, and gliogenesis (16). These connections are stimulated by the interaction with people and objects in the environment.

There is a variation in the age where children are able to perform certain tasks, and the frequencies of delays is determined by the cut-off point used for classification – often at the 5–10% level (17, 18). Among infants, physical development is reflected by control over motor skills. Constant repetition of these actions leads to increased physical strength and improved motor coordination (19). Within a few months, an infant is lifting or tracking an object by moving his head. By four or five months of age, a child can roll over; soon afterwards, he or she can sit upright in a high chair, and then gradually pull him- or herself into a sitting position. After learning to roll, the child may begin to crawl. Before learning to walk around the age of 12 months, an infant will learn to stand with help and pull him- or herself up (19). Cognitive development during infancy is typified by sensorimotor activity. Infants use their senses to process their environment. They also learn to communicate through crying, babbling, or making sounds.

In this analysis, we explored the association of maternal cell phone use during pregnancy with developmental milestone delays of motor, cognitive, and language milestones at age 6 and 18 months among offspring.

Methods

Subjects

The Danish National Birth Cohort (DNBC) began recruitment of pregnant women in March 1996 and concluded in November 2002 encompassing over 100 000 pregnancies (20, 21). Mothers and their offspring comprise two fixed cohorts to be followed over their lifetime. Data collection had been conducted by means of four telephone interviews – two during pregnancy and two at age 6 and 18 months (22). In 2005, an internet-based questionnaire administered to mothers to assess the child's health status was initiated when their offspring reached 7 years. Data on social conditions, family lifestyles, and childhood diseases were collected. This article is based on the information about children in the cohort born between 1997–2002 who had turned 7 years of age by January 2009 and whose mothers had a completed Age-7 questionnaire, either web- or paper-based.

Exposure

Questions regarding cell phone use during pregnancy (prenatal use) were included in the Age-7 questionnaire. Mothers reported whether they used a cell phone during their pregnancy for the child for whom the questionnaire was directed. Mothers also answered detailed questions on: (i) historical use of cell phone by mother (years since first use, trimester of use during pregnancy); (ii) average times spoken daily on phone during pregnancy; (iii) location of the phone when not in use (handbag or clothing pocket) during pregnancy; (iv) proportion of time that phone was powered on during pregnancy; and (v) use of earpiece (hands-free equipment) during pregnancy.

Covariates

Covariates of interest included parental history of developmental delays, pre-pregnancy body mass index (BMI), time to pregnancy, combined socio-occupational status of parents, prenatal intake of fish and alcohol, smoking, pre-eclampsia, gestational age, parents' ages at birth of child, birth weight, parity, household density, postpartum depression, breast feeding, amount of time spent with child, and child's time in daycare. Except for birth-related information, these covariates were collected at various

time points corresponding to a particular DNBC interview or questionnaire. Covariates related to birth were linked to participants' study information utilizing a unique central personal registration (CPR) number, which is issued to all persons who are born in or who immigrate to Denmark (23). The Danish national birth register provided data on gestational age, birth weight, and parity (24). Not all potential confounders (covariates) considered in the descriptive analysis were later used in the regression analyses. Only those covariates determined to be of interest were selected and are presented in the results section.

Outcomes

The DNBC's third and fourth interviews correspond to the age when the offspring turned age 6 and 18 months. They contained a series of questions developed by an experienced child neuropsychologist on the basis of existing validated instruments to assess motor, cognitive, and language milestone delays as reported by the mother. Given study conditions (large sample size and use of telephone interviews) this was seen as the best option. For the 6-month interview, mothers answered "yes or no" to 14 questions pertaining to their infant's development at interview time. Eight questions assessed cognitive and language development (ie, infant looks in the direction of sounds or voices, throws a toy to the floor, makes sounds while playing, mimics sounds, seeks attention from parent, expresses dislikes, puts objects in their mouth, and enjoys playing airplane). Motor development was assessed by a series of six questions (ie, the infant can hold up his/her head, sit with his/her back straight, roll from his/her back to front, sit upright on the floor, grab objects out of reach, and crawl on stomach). An overall delayed developmental score for motor (0–6 points) and cognitive/language (0–8 points) development was calculated by assigning 1 point for each "no" answered and summing over the group of questions. A higher score implied greater developmental delay.

In the 18-month interview, mothers answered 11 questions pertaining to delays in their infant. There were five questions pertaining to motor development delays, of which two questions assessed the age at which the infant could sit or walk without support. Those infants in the top 5% of the age distribution were categorized as "delayed" for these two milestones. This coincided with >9 months for sitting and >16 months for walking with no support. The other three "yes-or-no" questions assessed whether the infant could climb stairs, remove his/her socks and shoes, and drink from a cup or glass by his- or herself. Six cognitive and language development questions were also asked. These included fetching an object when requested, being able to make marks on paper or table, turning a picture upright in a book, using word-like sounds, putting two words together in a sentence, and being able to name or mention more than ten words. A developmental delay score for motor (0–5 points) and cognitive/language (0–6 points) development at 18 months was calculated by assigning 1 point for each "no" answer and summing over the group of questions.

To summarize motor, cognitive and language milestones, we defined "delayed" as those infants whose scores for motor or cognitive/language development corresponded to the highest 5% of the all infants for each of the 4 summary measures (motor delay at 6 and 18 months, respectively, and cognitive/language delay at 6 and 18 months, respectively).

Statistical analysis

All singleton, live births followed until the administration of the Age-7 questionnaire by January 2009 were included in this analysis. Comparisons were made between covariates collected and reported prenatal cell phone use. A binary logistic regression was used for the four dichotomized outcomes. The regression analysis was also restricted to children between 5–7 months of age at the time of the 6-month interview and children between 18–20 months by the 18-month interview. The logistic regression model estimated the odds ratio (OR) and 95% confidence intervals (95% CI) for developmental milestone delays, and adjustments included covariates controlling for potential confounders. Certain covariates (risk factors) were not associated with the outcome of interest in this analysis and were eliminated. In addition, 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 utilized during the model building process to develop a parsimonious model by manually eliminating variables at $P>0.05$.

Analysis was also conducted to consider potential dose–response patterns of prenatal cell phone exposure. Proxies of prenatal cell-phone-use intensity included the number of times per day speaking on the phone, location of phone when not in use, proportion of time phone was turned on, and the use of an earpiece with the cell phone. Reference categories were defined as the lowest category of exposure (ie, no use, used 0–1 times per day). When considering the location of phone when not in use, the reference group was "carried in bag" versus "carried in clothing pocket".

Results

These results are based on data collected from 41 541 singleton, live births for whom the mother completed an Age-7 questionnaire (approximately 60% of those

Table 1. Percent distribution of prenatal cell phone use by selected covariates (N=41 541)

	None (N=24 942)	Prenatal (N=13 938)	Do not know/ missing (N=2661)
Combined socio-occupational status for mother and father			
High	67.9	61.7	61.6
Medium	25.5	28.8	30.7
Low	2.5	4.6	3.6
Missing	4.1	4.9	4.1
Birth weight of child (grams)			
<2500	2.8	3.4	3.0
2500-2999	7.9	8.9	8.1
3000-3499	28.3	29.0	28.0
3500-3999	37.1	36.0	35.9
>3999	23.9	22.7	25.0
Year of birth			
1997–1999	50.2	32.0	28.4
2000–2002	49.7	67.9	71.5
Missing	0.1	0.0	0.1
Mother's age at child's birth (years)			
15–24	5.8	12.8	8.5
25–29	37.8	39.0	37.7
30–34	40.3	34.7	38.5
35–39	14.4	12.0	13.3
≥40	1.7	1.5	2.0
Gender of child			
Female	48.7	49.3	45.9
Male	51.2	50.7	54.0
Missing	0.1	0.0	0.1
Gestational age at birth (weeks)			
<37	4.5	5.2	4.3
37-41	86.2	85.4	86.3
≥42	9.0	9.2	9.1
Missing	0.3	0.2	0.3
Parity			
0	40.6	48.8	39.4
1	39.1	33.8	38.4
≥2	17.2	13.6	19.3
Missing	3.1	3.8	3.0
Child breastfed for at least the first six months			
Yes	62.4	56.4	61.2
No	16.0	22.4	19.4
Do not know/missing	21.6	21.2	19.4
Child in regular daycare outside the home at age 18-month interview			
Yes	70.0	69.2	69.3
No	9.5	7.5	10.4
Do not know/missing	20.5	23.3	20.3

eligible to participate by January 2009). Nearly 34% of mothers used a cell phone during pregnancy between 1997–2002 (table 1). Prenatal cell phone use doubled between 1998–2001 (from 21% to 46%, data not shown). For almost all covariates, the percent not known or missing was small and similar across the exposure groups. Variables collected from the 6- and 18-month interviews, which had approximately 20% missing or not known, included (i) parental history of speech and literacy problems, (ii) breastfeeding, (iii) postpartum depression, (iv) childcare, and (v) hours spent together. Prenatal exposure to cell phone use was associated with lower combined socio-occupational status, higher pre-pregnancy BMI, greater prenatal smoking, lower prenatal alcohol use, lower prenatal fish consumption, younger mothers and fathers at birth of child, and lower percentages of breastfeeding up to 6 months of age.

Table 2 presents the percents, OR and adjusted OR (OR_{adj}) for specific developmental milestone delays by prenatal cell phone use. Overall these specific milestones showed no association with the exposure. Of note only were 2 specific cognitive/language development milestone delays at 6 months ["does not throw toys to floor" (OR_{adj}=0.7) and "does not mimic sounds or voices" (OR_{adj}=0.9)] and another 2 at 18 months of age ["not putting two words together in a sentence" (OR_{adj}=0.9) and "not able to name or mention more than 10 words" (OR_{adj}=0.9)]. These results imply that infants of mothers who used a cell phone during pregnancy were less likely to have these types of delays.

Table 3 shows the distribution of overall developmental milestone delay scores for the four summary outcomes by prenatal cell phone use. Less than 2% of infants at 6 months of age had a cognitive/language developmental delay score of ≥3, and around 2% of infants at 6 months of age had a motor developmental delay score of ≥4. At age 18 months, around 2% of infants had a cognitive/language developmental delay score of ≥4, and between 3–4% of infants had a motor developmental delay score of ≥2 (table 3). The percentage of missing/not known was similar across exposure groups, and comprised 20–23% of all four measured outcomes.

OR were near the null value when comparing prenatal cell phone use to the four overall developmental delay outcomes among infants (table 4). At 6 months, the OR_{adj} were 0.8 (95% CI 0.7–1.0) for cognitive/language delay and 0.9 (95% CI 0.8–1.1) for motor development delay. At 18 months, associations were near the null for both overall developmental delays. These OR_{adj} that also controlled for corresponding developmental delays at 6 months were 1.1 (95% CI 0.9–1.3) and 0.9 (95% CI 0.8–1.0) for cognitive/language and motor development delay, respectively.

Among those mothers who reported using cell phones (N=13 938), 15% of mothers carried their cell phones in their clothing pockets, and 20% reported using an earpiece during pregnancy (data not shown). Both characteristics are indications that a cell phone was more likely to be worn closer to the womb by these types of mothers, yet associations with overall developmental milestone delays among infants were not observed. Also, 52% of mothers reported using a cell phone 0–1 times per day during their pregnancy (tables 5 and 6). And another 11% of mothers recalled speaking on the phone ≥4 times a day. Nearly half of mothers reported having the cell phone turned on 100% of the time. Associations of prenatal cell

Table 2. Percentages and odds ratios (OR) of specific developmental milestone delays among infants by prenatal cell phone use (N=41 541). [OR_{adj}= adjusted OR; 95% CI=95% confidence interval.]

	None	Prenatal	Do not know	OR	OR_{adj}	95% CI
Age 6 months						
Cognitive/language development delay						
Does not seek attention from parent	6.1	5.7	5.8	0.9	0.9	0.8–1.0 [a]
Does not expresses dislikes	8.3	8.5	8.5	1.0	1.0	0.9–1.1 [a]
Does not puts objects in mouth	0.4	0.3	0.4	0.8	0.9	0.6–1.3 [a]
Does not enjoy playing airplane	2.3	2.4	2.3	1.0	1.1	0.9–1.3 [a]
Does not look in the direction of sounds or voices	0.3	0.2	0.2	0.7	0.7	0.4–1.1 [a]
Does not throw toys to floor	5.6	4.0	5.7	0.7	0.7	0.7–0.8 [a]
Does not make sounds while playing	1.1	0.9	1.3	0.7	0.8	0.6–1.0 [a]
Does not mimic sounds or voices	19.2	17.5	19.1	0.8	0.9	0.8–0.9 [a]
Motor developmental delay						
Cannot hold head up	0.1	0.1	0.2	1.0	0.9	0.5–1.9 [b]
Cannot sit with back straight	8.0	7.5	7.3	0.9	0.9	0.8–1.0 [b]
Cannot roll from back to front	22.4	23.9	23.8	1.0	1.0	1.0–1.1 [b]
Cannot sit upright alone	56.3	55.9	58.8	0.9	0.9	0.9–1.0 [b]
Cannot grab for objects out of reach	1.2	1.0	1.2	0.8	0.8	0.7–1.1 [b]
Cannot crawl on stomach	36.6	36.0	38.1	1.0	1.0	0.9–1.0 [b]
Age 18 months						
Cognitive/language development delay						
Does not fetch an object when requested	1.3	1.2	1.6	1.0	1.0	0.8–1.2 [c]
Cannot make marks on paper or table	3.5	3.7	4.2	1.1	1.0	0.9–1.1 [c]
Does not turn pictures upright in books	25.9	35.3	37.5	1.0	1.0	0.9–1.0 [c]
Does not use word-like sounds	1.9	1.8	2.7	1.0	1.0	0.8–1.1 [c]
Does not put two words together in a sentence	43.2	39.7	45.6	0.9	0.9	0.8–0.9 [c]
Cannot name or mention more than 10 words	45.5	42.0	48.1	0.9	0.9	0.8–0.9 [c]
Motor developmental delay						
Cannot sit without support	3.8	3.8	4.1	1.0	1.0	0.9–1.2 [d]
Cannot walk without support	5.4	4.8	5.0	0.9	0.9	0.8–1.0 [d]
Cannot climb stairs	2.2	2.1	2.5	0.9	0.9	0.8–1.1 [d]
Cannot remove socks and shoes	13.8	12.8	15.3	0.9	0.9	0.9–1.0 [d]
Cannot drink from cup by themselves	0.8	0.8	1.1	1.1	1.1	0.9–1.5 [d]

[a] Adjusted for gender of child, combined socio-occupational status, gestational age, parity, and child's year of birth.
[b] Adjusted for gender of child, combined socio-occupational status, mother's age at birth, gestational age, and child's birth weight.
[c] Adjusted for gender of child, combined socio-occupational status, gestational age, and breast feeding up to six months of age.
[d] Adjusted for gender of child, combined socio-occupational status, mother's age at birth, child's birth weight, and childcare outside home at 18 months.

Table 3. Percent distribution of overall developmental milestone delays among infants by prenatal cell phone use (N=41 541).

	None (N=24 942)	Prenatal (N=13 938)	Do not know/ Missing (N=2661)
Age 6 months milestones scores			
Cognitive/language developmental delay			
Low (0–2)	76.5	77.7	79.3
High (3–8)	1.8	1.4	1.7
Do not know/missing	21.7	20.9	19.0
Motor developmental delay			
Low (0–3)	76.2	77.2	78.7
High (4–6)	2.1	2.0	2.3
Do not know/missing	21.7	20.8	19.0
Age 18 months milestones scores			
Cognitive/language developmental delay			
Low (0–3)	77.6	74.7	77.3
High (4–6)	1.9	2.0	2.4
Do not know/missing	20.5	23.3	20.3
Motor developmental delay			
Low (0–1)	75.4	73.2	74.9
High (2–5)	3.6	3.1	4.2
Do not know/missing	21.0	23.7	20.9

Table 4. Odds ratio (OR) for overall developmental milestone delays among infants according to prenatal cell phone use (N=41 541). [95% CI=95% confidence interval; OR_{adj}=adjusted OR.]

	OR	OR_{adj}	95% CI
Age 6 months outcomes			
Cognitive/language development delay	0.8	0.9	0.7–1.0 [a]
Motor development delay	0.9	0.9	0.8–1.1 [b]
Age 18 months outcomes			
Cognitive/language development delay	1.1	1.0	0.9–1.2 [c]
Cognitive/language development delay	1.1	1.1	0.9–1.3 [d]
Motor development delay	0.9	0.9	0.8–1.0 [e]
Motor development delay	0.9	0.9	0.8–1.0 [f]

[a] Adjusted for child's gender, combined social-occupational status, gestational age, parity, and child's year of birth.
[b] Adjusted for child's gender, combined social-occupational status, mother's age at birth, gestational age, and child's birth weight.
[c] Adjusted for child's gender, combined social-occupational status, gestational age, and breast feeding up to six months of age.
[d] Adjusted for child's gender, combined social-occupational status, mother's age at birth, gestational age, and cognitive/language developmental delay at six months of age.
[e] Adjusted for child's gender, combined social-occupational status, mother's age at birth, child's birth weight, and childcare outside home at 18 months.
[f] Adjusted for child's gender, combined social-occupational status, mother's age at birth, child care outside the home at 18 months and motor developmental delay at six months of age.

Table 5. Odds ratio (OR) for overall developmental milestone delays at age *6 months* among infants according to mother's characteristics for prenatal cell phone use (N=13 938). [95% CI=95% confidence interval; OR_{adj}=adjusted OR.]

	N	%	OR	P-value	OR_{adj}	P-value	95% CI
Cognitive/language development delay							
Times spoken per day				0.3		0.3	
0–1	7444	52.2	1.0		1.0		
2–3	3778	26.5	1.0		1.0		0.7–1.4 [a]
≥4	1529	10.7	0.8		0.8		0.4–1.3 [a]
Missing	1489	10.6	-		-		
Percentage of time turned on				0.3		0.4	
0	1129	7.9	1.0		1.0		
<50	1825	12.8	1.1		1.1		0.6–1.9 [a]
50–99	4305	30.2	0.8		0.9		0.5–1.6 [a]
100	6877	48.3	1.1		1.0		0.5–2.0 [a]
Missing	104	0.8	-		-		
Motor development delay							
Times spoken per day				0.2		0.1	
0–1	7444	52.2	1.0		1.0		
2–3	3778	26.5	0.8		0.8		0.5–1.0 [b]
≥4	1529	10.7	0.6		0.6		0.3–1.0 [b]
Missing	1489	10.6	-		-		
Percentage of time turned on				0.2		0.2	
0	1129	7.9	1.0		1.0		
<50	1825	12.8	1.3		1.3		0.8–2.7 [b]
50–99	4305	30.2	1.0		1.1		0.6–1.8 [b]
100	6877	48.3	1.1		1.1		0.6–2.0 [b]
Missing	104	0.8	-		-		

[a] Adjusted for gender of child, combined social-occupational status, gestational age, parity, and child's year of birth.

[b] Adjusted for gender of child, combined social-occupational status, mother's age at birth, gestational age, and child's birth weight.

Table 6. Odds ratio (OR) for overall developmental milestone delays at age *18 months* among infants according to mother's characteristics for prenatal cell phone use (N=13 938). [95% CI=95% confidence interval; OR_{adj}=adjusted OR; NA=not available.]

	N	%	OR	P-value	OR_{adj}	P-value	95% CI	OR_{adj}	P-value	95% CI
Cognitive/language development delay										
Times spoken per day				0.3		0.3			0.6	
0–1	7444	52.2	1.0		1.0			1.0		
2–3	3778	26.5	0.9		0.9		0.6–1.2 [a]	0.9		0.6–1.3b
≥4	1529	10.7	0.7		0.7		0.4–1.2 [a]	0.9		0.5–1.6 [b]
Missing	1489	10.6	.		.			.		
Percentage of time turned on				0.7		0.7			0.6	
0	1129	7.9	1.0		1.0			1.0		
<50	1825	12.8	1.1		0.9		0.6–1.6 [a]	1.2		0.7–2.3 [b]
50–99	4305	30.2	1.0		0.9		0.5–1.5 [a]	1.2		0.5–2.2 [b]
100	6877	48.3	1.1		1.1		0.6–2.0 [a]	1.5		0.7–3.0 [b]
Missing	104	0.8	.		.			.		
Motor development delay										
Times spoken per day				NA		NA			NA	
0-1	7444	52.2	1.0		1.0			1.0		
2-3	3778	26.5	0.7		0.7		0.6–1.0 [c]	0.7		0.5–1.0 [d]
≥4	1529	10.7	1.1		1.1		0.8–1.5 [c]	1.2		0.8–1.8 [d]
Missing	1489	10.6	.		.			.		
Percentage of time turned on				0.5		0.5			0.4	
0	1129	7.9	1.0		1.0			1.0		
<50	1825	12.8	1.0		1.0		0.7–1.5 [c]	1.1		0.7–1.8 [d]
50-99	4305	30.2	1.0		1.0		0.7–1.6 [c]	1.2		0.8–2.0 [d]
100	6877	48.3	1.2		1.2		0.8–2.0 [c]	1.3		0.8–2.3 [d]
Missing	104	0.8	.		.			.		

[a] Adjusted for gender of child, combined social-occupational status, gestational age, and breastfeeding up to six months of age.

[b] Adjusted for gender of child, combined social-occupational status, mother's age at birth, gestational age, and cognitive/language developmental delay at six months of age.

[c] Adjusted for gender of child, combined social-occupational status, mother's age at birth, child's birth weight, and child care outside home at 18 months.

[d] Adjusted for gender of child, combined social-occupational status, mother's age at birth, child care outside the home at 18 months and motor developmental delay at six months of age.

phone use characteristics were compatible with the null for all 4 outcomes at 6 and 18 months of age and did not indicate any dose–response relationship.

Discussion

We found no evidence to support an overall association or dose–response association with cell phone use during pregnancy and motor or cognitive/language developmental delays among children at 6 or 18 months of age. Estimates were compatible with values for no effect. Various known risk factors for developmental delays were analyzed, and we did observe associations with developmental delay outcomes in our data.

Vrijheid at el (25) published similar results reporting no association between prenatal exposure to cell phone use and neurodevelopment at 14 months of age among offspring. As in our results, both mental and psychomotor scores were not associated with exposure even when considering the reported number of calls spoken per day (dose–response).

When modeling specific absorption rates of RF to the womb of pregnant mothers, research suggests that exposures are likely low and not high enough to elevate the body temperature (26–28). But this modeling is based on numerous assumptions and extrapolations. And possible non-thermal effects of RF still remain of interest.

Throughout the study, mothers were not aware of our research hypothesis. The timing of data collection between interviews and questionnaires are far enough apart that

mothers with delayed development children were unlikely systematically to under- or overestimate using a cell phone during pregnancy compared to mothers of children with no delayed development. In general, research looking at the agreement between self-reported cell phone use and usage measured by billing or subscription records concludes that individuals tend to overestimate call duration and underestimate the number of calls (29, 30).

As participation in each round of interviews and questionnaires was voluntary for mothers, it is possible that data were collected for mothers and children participating in the DNBC at only some time points such as 6 months and age 7 years and not have information available at 18 months for the infant. Thus we observed a consistent proportion of infants for whom data concerning the outcome was missing (19–22%), but it does not appear that missing data varied differentially for covariates, which might have indicated systematic error due to selection.

Developmental delays are not routinely captured from hospitalization records except for the most severe of conditions (ie, autism, mental retardation, etc.). Thus it is difficult to use an independent data source that captures the outcomes for this research question to validate our data, since these outcomes are more common and less severe – not receiving or requiring specific medical attention. It should also be noted that the DNBC's assessment for developmental delays was only until age 18 months. Associations of prenatal cell phone use and delays up to the age of 5 years were not assessed.

As the DNBC is a large cohort study, any direct clinical case ascertainment is cost prohibitive. Using interviews and questionnaires conducted by mothers is a more efficient method of gathering information. Since interviews were conducted in a timely manner, mothers would be reporting milestone attainment in real time. In fact, parental reports of developmental delays appear to strongly predict the results of detailed clinical inventories, brain imaging, as well as genetic testing completed for the assessment of developmental milestone delays in the clinical setting (31). Thus we are reassured that direct, timely assessments from mothers is a valid approach in collecting data for this outcome.

Reporting of developmental milestones need not pick up subtle delays in brain development or delays that first manifest later in life. It is possible that more sensitive psychological instruments would have detected delays that this study did not capture, but we have no reason to expect such an effect. A study based upon in-person psychological testing would furthermore have shortcomings such as more non-responders and measurement error related to different levels of contact between a given psychologist and child.

Based upon the results of this study, there does not appear to be any evidence to support an association between prenatal cell phone use and motor and cognitive/language developmental milestone delays among children before the age of two.

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