

Maternal mobile phone use and children's neurocognitive development

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Objectives: Today, mobile phone use is common and has increased rapidly in many countries. The health effects of exposure to mobile phone use on children are controversial. We described maternal mobile phone use from pregnancy until the 12 months post-birth and examined the association between exposure to mobile phone use and the children's neurocognitive development in the general population in Taipei, Taiwan. **Methods:** The study was a part of the Taiwan Birth Panel Study. A total of 133 pairs of parents and their singleton child were recruited into this study. We used the Comprehensive Developmental Inventory for Infants and Toddlers (CDIIT) and Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) to assess child neurocognitive development. We also assessed the intelligence of the mothers using the Standard Progressive Matrices Plus (SPM+). Mothers completed questionnaires to report their mobile phone use. Regression modeling was used to estimate the association between mobile phone exposure and children's neurocognitive development. **Results:** Most of the mothers answered less than 3 phone calls per day, and the call duration was less than 3 minutes for each phone call from pregnancy until 12 months post-birth. We found no significant association between maternal mobile phone use and neurocognitive development in young children. **Conclusions:** There is no convincing evidence that maternal mobile phone use has an adverse effect on the neurocognitive development of young children. Prospective research using a personal exposure assessment is needed to elucidate a causal relationship. (*Taiwan J Public Health*. 2012;**31**(5):436-445)

Key words: prenatal exposure, mobile phone, neurocognitive development, young children

INTRODUCTIONS

Today, mobile phone use is common and has increased rapidly in many countries. Globally, there were nearly 5 billion mobile phone subscribers in 2010[1]. In Taiwan, more than 90% of people have mobile phones[2]. Therefore, the risk of exposure to radiofrequency fields is increasing, especially in children. Children are more susceptible to radiofrequency fields and may be more vulnerable than adults because of their developing nervous systems. Furthermore, children are exposed to radiofrequency fields at an earlier age and have a longer lifetime exposure than adults[3,4].

The World Health Organization emphasizes that studies that investigate the effects of

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child mobile phone use on cognition neurodevelopment are a high priority[5]. A few studies have evaluated the association between mobile phone use and child neurodevelopment, but the results are not consistent. Divan et al. showed that prenatal and postnatal exposure to mobile phones was associated with emotional and hyperactivity problems at 7 years of age[6]. Another study found little evidence of the effect of maternal mobile phone use on early neurodevelopment at 14 months[7]. On the other hand, some studies did not find specific evidence for adverse effects of maternal mobile phone use on the early neurodevelopment of children[3,8].

The purpose of this study is to describe maternal mobile phone use during pregnancy and at postnatal ages up to 12 months. Evidence for adverse developmental effects of mobile phone use on child neurodevelopment is therefore limited and controversial. Another purpose of this study is to examine the association between prenatal and postnatal mobile phone use and early-childhood neurodevelopment and intelligence in young children.

MATERIALS AND METHODS

Study population

This study was based on the Taiwan Birth Panel Study (TBPS), a prospective cohort study that was conducted between April 2004 and January 2005[9]. Informed consent was obtained from study participants before delivery to collect maternal blood, umbilical cord blood, and questionnaires. After delivery, all subjects were interviewed about their prenatal lifestyle by trained interviewers. We followed up with the children at 2, 5 and 7 years old. The postnatal questionnaires were completed by primary caregivers at each follow-up appointment. Neurodevelopment

and intelligence tests were conducted at ages 2 and 7, respectively. The Ethical Committee of National Taiwan University Hospital approved the protocols used in this study.

We only included singleton infants, and none of the participants (mothers) were smokers. We also excluded preterm infants, subjects who did not complete the neurodevelopment and intelligence tests at 2 and 7 years of age, respectively, and subjects without mobile phone data. After applying the exclusion criteria, 133 pairs of subjects remained in our study.

Mobile phone exposure

When the subjects were 5 years of age, we modified the questionnaires for mobile phone exposure from the Danish National Birth Cohort (DNBC) study[10]. The questionnaire focused on mobile phone use among mothers during pregnancy (three trimesters) and at postnatal ages up to 12 months. Mothers reported their use of mobile phones (average daily phone calls, average time spoken per phone call), use of hands-free equipment from pregnancy to postnatal ages up to 12 months, and the location of the mobile phone during pregnancy (clothing pocket or purse). In the questionnaire, the daily number of calls was divided into three groups (less than 3 calls, 4 to 10 calls, and over 10 calls) and the amount of time spoken per phone call was divided into four groups (below 1 minute, 1 to 3 minutes, 4 to 10 minutes, and over 10 minutes). To estimate the cumulative dose of mobile phone use, we used the median to represent each exposure group and multiplied daily phone calls by time spoken per phone. The dose of mobile phone use during pregnancy was the sum of the three trimesters. The postnatal dose of mobile phone use at the child's first year of age was the sum of the 12 months of the year.

Therefore, the cumulative dose was used to estimate the prenatal and postnatal mobile phone exposure.

Child neurodevelopment

Child neurodevelopment was assessed at 2 years of age using the Comprehensive Developmental Inventory for Infants and Toddlers (CDIIT)[11]. The CDIIT was designed to assess development in cognitive, motor, gross motor, fine motor, language, social, and self-help areas. The applicable age range of the CDIIT is from 3 to 71 months. The standardization used 3,703 randomly selected Taiwanese infants aged 3 to 71 months. The CDIIT has good test-retest reliabilities [11] and an acceptable concurrent validity with the Bayley scales of Infant Development-II (BSID-II), which is commonly used worldwide[12].

The assessment of the CDIIT was comprised two assessments: one by physical therapists and one by a questionnaire. The cognitive and motor subtests and part of the language subtest were individually and directly evaluated by the testers. In addition, the social and self-help subtests and some items of the language subtest were scored from the questionnaires, which were completed by the main caregivers. The results of the CDIIT test, the developmental quotients (DQ), were obtained for the whole test (whole DQ), five subtests (cognitive DQ, motor DQ, language DQ, social DQ, and self-help DQ), and the two subdomains (gross motor DQ and fine motor DQ). Generally, the mean DQ is 100[11]. According to the CDIIT manual, a DQ of 85 or above is within normal limits, and children whose DQ is below 70 or within 70-84 are classified as delayed or borderline, respectively[12].

Children's and maternal intelligence

We used the Chinese version of the Wechsler Intelligence Scale for Children, fourth edition (WISC-IV)[13], the universally acknowledged tool to evaluate children's intelligence at 6 to 7 years of age. The WISC-IV has five domains: Full Scale (FSIQ), Verbal Comprehension Index (VCI), Perceptual Reasoning Index (PRI), Working Memory Index (WMI), and Processing Speed Index (PSI). Trained testers assessed the WISC-IV, and we used the age-corrected scores of 5 domains. Normally, the mean score of the WISC-IV is 100, and the standard deviation is 15.

Mothers' intelligence was assessed using the Standard Progressive Matrices Plus (SPM+) test[14]. There are 60 questions in the SPM+ test, and the subjects have to answer as many questions as they are able in 30 minutes. This test is applicable from 12 years of age to adulthood. The highest score of the SPM+ test is 60. In the regression models, we adjusted the total score of the mother's intelligence.

Home observation for measurement of the environment inventory (HOME Inventory)

At 2 years of age, we also used the HOME Inventory to measure the caregiving environment. The HOME Inventory is designed to measure the quality and quantity of stimulation and support available to a child in the home environment[15]. The Infant/Toddler HOME Inventory (IT-HOME) tests children from birth to age 3, and comprises 45 items clustered into six subscales: parental responsiveness, acceptance of child, organization of the environment, learning materials, parental involvement, and variety of experience. For the HOME Inventory, the subjects were observed, and the main caregivers were interviewed by

trained staff. The missing data were substituted with the Mode of the HOME scores in this study.

Statistical analysis

We used linear and logistic regression models to estimate the association between mobile phone use and child neurodevelopment. Maternal mobile phone use was divided into two groups: during pregnancy and birth to 12 months post-birth. According to the sample distribution, high exposure was defined as the fourth quartile of the cumulative dose, and low exposure was defined as all other quartiles. In the logistic regression models, the cut-points of the 8 areas of the CDIIT DQ and the 5 domains of the WISC-IV test were the first quartile of the distribution.

We adjusted for some potential confounders in the models, including maternal age, maternal education, family income, infant gender, lead levels in the cord blood, HOME score, and prenatal ETS exposure as reported on a questionnaire. In the models of postnatal mobile phone exposure, we also adjusted for postnatal ETS exposure and the amount of time a mother accompanied her child per day. Moreover, we adjusted for maternal intelligence in the models of mobile phone use and children's intelligence. The level of significance of this study is $p < 0.05$. All statistical analyses were conducted with SAS 9.2 (SAS Institute Inc., Cary, NC).

RESULTS

In this analysis, 133 pairs of mothers and children had complete mobile phone use data and finished the CDIIT and the WISC-IV test. Most mothers had completed some higher education and only 5% of mothers consumed alcohol during pregnancy. In addition, all of the infants were full-term births, and only 2 infant birth weights were below the normal range

(birth weights ≥ 2500 g). These subjects were from the general population. The mean DQs of 8 tests of the CDIIT and the mean scores of the WISC-IV were all within normal ranges (DQs ≥ 85 ; score of the WISC-IV ≥ 100) (Table 1). In both prenatal and postnatal mobile phone use, more than half of the mothers took less than 3 phone calls per day, and the call duration was less than 3 minutes per call. Furthermore, more than 85% of the mothers did not use hands-free equipment, and 94% of mothers put their phones in their purses during pregnancy (Table 2). However, there were no significant findings between maternal mobile phone use and child neurodevelopment and intelligence (Table 3 and Table 4).

DISCUSSIONS

Our study did not find any evidence to support that maternal mobile phone use from pregnancy to 12 months after birth adversely affected children's neurocognitive development. Two studies published similar results reporting no association between prenatal mobile phone use and early-childhood neurodevelopment at 6, 14 and 18 months[7,8]. Our results are consistent with previous studies, even when various potential confounders for neurodevelopment were analyzed and adjusted.

Most mothers answered less than 3 phone calls per day during pregnancy, but the proportion of heavier users (≥ 4 phone calls per day) in our study is slightly higher than the population in western countries[3,6-8]. Mothers used mobile phones directly, and only a few mothers ever used hands-free equipment. Although the cumulative dose was high, the children's neurodevelopment and intelligence remained within normal limits.

So far, there is no specific biological mechanism that explains an association between mobile phone use and adverse effects on neurodevelopment. Some studies have

Table 1. Characteristics of the study population

Characteristic	All population (n = 133) mean \pm standard deviation
Maternal characteristics	
Age (years)	33.0 \pm 3.9
Maternal education (%)	
High school and below	36.1
University and above	63.9
Prenatal ETS ^a exposure (%)	24.1
SPM+ ^b total score	39.6 \pm 4.5
Family characteristics	
Annual family income	
\geq NT\$ 1,000,000	34.6
< NT\$ 1,000,000	65.4
HOME score ^c (point)	41.2 \pm 2.3
Mother accompany with child per day (hr)	7.4 \pm 5.2
Infant characteristics	
Gender (%)	
Male	52.6
Female	47.4
Birth weight (g)	3279.8 \pm 396.1
Gestational age (week)	39.0 \pm 1.1
Lead in cord blood (μ g/L)	1.26 \pm 0.66
Postnatal ETS exposure (%)	31.6
CDIIT ^d (DQ ^e)	
Whole Test	100.0 \pm 12.1
Cognitive	99.7 \pm 21.0
Language	101.8 \pm 12.8
Motor	88.5 \pm 11.8
Gross-motor	86.0 \pm 13.7
Fine-motor	95.6 \pm 10.9
Social	108.8 \pm 14.8
Self-help	100.6 \pm 14.1
WISC-IV ^f	
FSIQ (Full Scale IQ)	109.4 \pm 12.0
VCI (Verbal Comprehension Index)	107.8 \pm 13.4
PRI (Perceptual Reasoning Index)	110.0 \pm 15.0
WMI (Working Memory Index)	110.0 \pm 14.6
PSI (Processing Speed Index)	100.5 \pm 12.2

^a ETS, environmental tobacco smoke ^b Standard Progressive Matrices ^c HOME, Home Observation for Measurement of the Environment ^d CDIIT, Comprehensive Developmental Inventory for Infants and Toddlers ^e DQ, developmental quotients ^f WISC-IV, Wechsler Intelligence Scale for Children, 4th edition

focused on the molecular and cellular effect of radiofrequency exposure. Electromagnetic frequency may affect cell cycles, causing cell

damage[16,17]. Brzezinski suggested that if a mobile phone is close to a person's head when talking, the radiofrequency fields from a mobile

Table 2. Distribution of maternal mobile phone use from pregnancy to 12 months (N = 133)

	During pregnancy No. (%)	Birth to 12 months No. (%)
Daily phone calls		
< 3	73 (54.9)	74 (55.6)
4-10	49 (36.8)	49 (36.8)
> 10	11 (8.3)	10 (7.5)
Time spoken per phone calls (min)		
< 1	39 (29.3)	39 (29.3)
1-3	80 (60.2)	75 (56.4)
4-10	13 (9.8)	18 (13.5)
> 10	1 (0.7)	1 (0.8)
Prenatal cumulative dose of mobile phone use (hr)		
≤ 63	114 (85.7)	--
> 63	19 (14.3)	--
Postnatal cumulative dose of mobile phone use (hr)		
≤ 84	--	111 (83.5)
> 84	--	22 (16.5)
Use of hands-free equipment		
Yes		19 (14.3)
No		114 (85.7)
Location of mobile phone		
Clothing pocket		8 (6.0)
In the bag		125 (94.0)

Values are numbers and percentages.

Table 3. Linear regression models of the child neurodevelopment and mobile phone use (N=133)

Mobile phone use	During pregnancy (≤ 63 hr vs. >63 hr)				Birth to 12 months (≤ 84 hr vs. >84 hr)			
	Crude β (SE)	p value	Adjusted β (SE)	p value	Crude β (SE)	p value	Adjusted β (SE)	p value
CDIIT DQ								
Whole DQ	-2.18 (2.99)	0.4669	-0.74 (2.77)	0.7910	1.61 (2.62)	0.5390	1.41 (2.67)	0.5993
Cognitive DQ	-3.93 (5.32)	0.4618	-2.05 (5.38)	0.7042	0.30 (5.08)	0.9523	0.50 (5.15)	0.9234
Language DQ	-6.03 (3.13)	0.0562	-3.79 (2.97)	0.2158	-0.43 (2.83)	0.8800	-0.28 (2.89)	0.9237
Motor DQ	2.22 (3.00)	0.4615	2.56 (3.01)	0.3969	-0.28 (2.85)	0.9214	-0.10 (2.89)	0.9717
Gross-motor DQ	1.30 (3.42)	0.7046	1.43 (3.49)	0.6825	-1.50 (3.30)	0.6498	-1.26 (3.34)	0.7066
Fine-motor DQ	1.03 (2.78)	0.7126	1.79 (2.68)	0.5068	-0.03 (2.54)	0.9910	0.29 (2.57)	0.9097
Social DQ	-0.85 (3.67)	0.8171	0.07 (3.55)	0.9850	0.48 (3.36)	0.8857	-0.74 (3.35)	0.8262
Self-help DQ	-0.39 (3.52)	0.9128	0.62 (3.37)	0.8549	4.34 (3.17)	0.1729	4.41 (3.23)	0.1756
WISC-IV								
Full Scale IQ	-2.37 (2.99)	0.4294	-2.32 (2.94)	0.4317	-3.93 (2.82)	0.1662	-2.80 (2.81)	0.3222
Verbal Comprehension Index	3.05 (3.38)	0.3680	3.83 (3.25)	0.2416	1.32 (3.20)	0.6817	2.46 (3.19)	0.4407
Perceptual Reasoning Index	-4.91 (3.67)	0.1836	-5.46 (3.69)	0.1416	-4.99 (3.47)	0.1535	-3.92 (3.54)	0.2705
Working Memory Index	-3.99 (3.65)	0.2767	-4.30 (3.65)	0.2411	-6.47 (3.43)	0.0616	-6.20 (3.48)	0.0768
Processing Speed Index	-0.74 (3.12)	0.8119	-0.80 (3.06)	0.7950	-1.84 (2.94)	0.5342	-1.19 (2.98)	0.6917

^a Models adjusted for maternal education, maternal age, family income, infant sex, lead levels in the cord blood, HOME score, prenatal ETS exposure as reported on a questionnaire, and mothers intelligence.

^b Models adjusted for maternal education, maternal age, family income, infant sex, lead levels in the cord blood, HOME score, prenatal ETS exposure and postnatal ETS exposure as reported on a questionnaire, mother accompany with child per day (hr), and mothers intelligence.

Table 4. Logistic regression models of the child neurodevelopment and mobile phone use (N=133)

Mobile phone use	During pregnancy (≤ 63 hr vs. >63 hr)				Birth to 12 months (≤ 84 hr vs. >84 hr)			
	Crude OR (95%CI)	p value	Adjusted ^a OR (95%CI)	p value	Crude OR (95%CI)	p value	Adjusted ^b OR (95%CI)	p value
CDIIT DQ								
Whole DQ	2.19 (0.78-6.16)	0.1383	1.92 (0.59-6.19)	0.2776	1.29 (0.46-3.65)	0.6308	1.07 (0.32-3.53)	0.9170
Cognitive DQ	1.00 (0.30-3.29)	1.0000	0.92 (0.25-3.33)	0.8960	1.13 (0.38-3.37)	0.8330	0.81 (0.22-2.91)	0.7405
Language DQ	3.56 (1.30-9.78)	0.0137 [*]	3.38 (1.00-11.42)	0.0504	2.65 (1.01-6.96)	0.0481	1.75 (0.54-5.71)	0.3509
Motor DQ	1.21 (0.40-3.67)	0.7379	1.06 (0.31-3.60)	0.9316	2.19 (0.82-5.84)	0.1186	2.21 (0.72-6.82)	0.1670
Gross-motor DQ	1.33 (0.40-4.46)	0.6405	1.35 (0.37-4.89)	0.6476	2.77 (0.98-7.85)	0.0552	2.89 (0.90-9.28)	0.0747
Fine-motor DQ	1.25 (0.38-4.18)	0.7131	1.22 (0.31-4.81)	0.7813	1.01 (0.31-3.31)	0.9854	0.69 (0.16-2.93)	0.6111
Social DQ	1.21 (0.40-3.67)	0.7379	1.09 (0.33-3.68)	0.8842	0.96 (0.32-2.86)	0.9441	0.86 (0.26-2.90)	0.8102
Self-help DQ	1.15 (0.38-3.49)	0.8039	0.99 (0.30-3.26)	0.9881	0.45 (0.12-1.62)	0.2202	0.38 (0.09-1.55)	0.1753
WISC-IV								
Full Scale IQ	1.64 (0.57-4.76)	0.3601	1.36 (0.44-4.18)	0.5902	1.69 (0.62-4.62)	0.3050	1.07 (0.36-3.21)	0.9041
Verbal Comprehension Index	0.40 (0.09-1.84)	0.2379	0.36 (0.08-1.71)	0.1982	0.33 (0.07-1.49)	0.1490	0.28 (0.06-1.34)	0.1099
Perceptual Reasoning Index	2.73 (0.99-7.53)	0.0529	2.89 (0.96-8.68)	0.0581	2.65 (1.01-6.96)	0.0481	2.17 (0.75-6.27)	0.1546
Working Memory Index	2.04 (0.70-6.00)	0.1933	2.12 (0.68-6.64)	0.1978	2.77 (1.02-7.52)	0.0459	2.63 (0.89-7.77)	0.0807
Processing Speed Index	0.83 (0.22-3.11)	0.7827	0.67 (0.17-2.65)	0.5715	1.01 (0.31-3.31)	0.9854	0.70 (0.20-2.49)	0.5860

Cut-points of the CDIIT DQ and the WISC-IV test were the first quartile.

^a Models adjusted for maternal education, maternal age, family income, infant sex, lead levels in the cord blood, HOME score, prenatal ETS exposure as reported on a questionnaire, and mothers intelligence.

^b Models adjusted for maternal education, maternal age, family income, infant sex, lead levels in the cord blood, HOME score, prenatal ETS exposure and postnatal ETS exposure as reported on a questionnaire, mother accompany with child per day (hr), and mothers intelligence.

^{*} $p < 0.05$

phone may affect signaling in the unmyelinated nerves and influence melatonin secretion. Furthermore, diverse changes in maternal metabolism or the sex hormone environment may affect development of the fetal brain, leading to behavioral problems[18]. Only one animal study found that the mice exposed *in utero* to radiofrequency were hyperactive, had decreased memory, and decreased anxiety, possibly because the electromagnetic frequency impaired nervous transmission[19]. The exposure dose used in this animal study was higher and different from the exposure in the human studies. Therefore, extrapolation of the results from the animal model to humans is limited.

During pregnancy, more than 90% of mothers keep their mobile phone in their purse

when not in use, so the mobile phone did not come close to the fetus. To our knowledge, the intensity of a radiofrequency field would be reduced with distance. In addition, the call duration per phone call of most mothers was less than 3 minutes. Accordingly, the prenatal exposure to mobile phone use may not be high enough to affect the children's neurocognitive development in this study. Maternal education is an important predictor of the cognitive development of young children, and the child of mothers with higher education had better performance on development[20,21]. The mothers in our study were more highly educated and spent more with their children than average. These mothers might take better care of their children, improving their postnatal neurocognitive development.

An important limitation of this study is recall bias because we used retrospective questionnaires to estimate past maternal mobile phone use. We considered that mobile phone use might be a habit and that the users did not change much in different periods. A previous study has shown good accuracy for recalled self-reporting mobile phone use, although individuals tend to underestimate the number of calls and overestimate the call duration[22]. Another limitation is that we did not ask about the children's use of mobile phones. One study found that children had a high risk for adverse health effects if they had both prenatal exposure and directly used a mobile phone postnatally[15]. In this study, mobile phones were most likely rarely used by children due to the young age of the sample, so their postnatal dose of mobile phone exposure might be lower than in previous studies.

Conclusions

Based upon the results of this study, the dose of maternal mobile phone use is slightly higher than in other studies that use objective tools to estimate the children's neurocognitive development. However, among these young children, we did not find evidence to support an association between maternal mobile phone use and children's neurocognitive development. Prospective research using personal exposure assessment is needed to elucidate a causal relationship.

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母親手機使用與孩童神經認知行為發展

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目標：手機使用已越趨頻繁，然而手機之電磁波對於孩童健康發展之不良影響仍有爭議。本研究之目的為，描述從妊娠期到產後一年之母親手機使用情形，並進一步探討其手機使用量和孩童神經認知行為發展之影響。**方法：**自2004年至2005年間，收集來自大台北地區不同醫療院所的產婦及其新生兒為研究對象，最終納入133對產婦及其新生兒進行分析。我們使用「嬰幼兒綜合發展測驗」(Comprehensive Developmental Inventory for Infants and Toddlers, 簡稱CDIIT)以及「魏氏兒童智力量表第四版」(Wechsler Intelligence Scale for Children-Fourth edition, 簡稱WISC-IV)評估孩童之神經認知行為發展。另外，我們也使用「瑞文氏圖形推理測驗」(Standard Progressive Matrices, 簡稱SPM+)評估母親智力。藉由自填式問卷評估母親的手機使用量，再使用迴歸模式進行統計分析。**結果：**從妊娠期至產後一年，多數的母親每天手機的接聽通數皆少於3通，且每通電話之通話時間皆少於3分鐘。研究結果並未發現手機暴露對於孩童的神經行為發展有不良之影響。**結論：**目前仍未有明確的證據足以證明手機之暴露會造成孩童神經行為之不良影響，未來仍需要更多的研究針對此議題進行探討。(台灣衛誌 2012；31(5)：436-445)

關鍵詞：產前暴露、手機、神經認知行為發展、孩童

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