Maternal occupation and the risk of birth defects: an overview from the National Birth Defects Prevention Study

M L Herdt-Losavio,[1] S Lin,[1] B R Chapman,[1] M Hooiveld,[2] A Olshan,[3] X Liu,[1] R D DePersis,[1] J Zhu,[1] C M Druschel[1]

[1] New York State Department of Health, Center for Environmental Health, Troy, New York, USA; [2] Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands; [3] Department of Epidemiology, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

Correspondence to: Dr Michele L Herdt-Losavio, New York State Department of Health, Center for Environmental Health, Bureau of Environmental and Occupational Epidemiology, 547 River Street, Room 200, Troy, NY 12180, USA; mlh06@health.state.ny.us

Accepted 6 August 2009

ABSTRACT

Objectives: To examine the association between a spectrum of 24 maternal occupations and 45 birth defects for hypothesis generating purposes.

Methods: Cases of isolated and multiple birth defects (n = 8977) and all non-malformed live-born control births (n = 3833) included in the National Birth Defects Prevention Study (NBDPS) with estimated dates of delivery from 1 October 1997 through 31 December 2003 were included. A computer-assisted telephone interview with mothers was conducted. Occupational coding using the 2000 Standard Occupational Classification System and the 1997 North American Industry Classification System was completed for all jobs held by mothers. Jobs held from 1 month before pregnancy to the end of the third pregnancy month were considered exposures. Logistic regression models were run, adjusted for potential confounders. We also used a Bayesian approach to logistic regression.

Results: Approximately 72% of case mothers and 72% of control mothers in the NBDPS were employed. Several occupational groups were positively associated with one or more birth defects, including janitors/cleaners, scientists and electronic equipment operators. Using standard logistic regression, we found 42 (26 for Bayesian) significantly elevated risks of birth defects in offspring of working mothers. In addition, several other occupational groups were found to be negatively associated with one or more birth defects, including teachers and healthcare workers. Using standard logistic regression, we found 12 (11 for Bayesian) significantly reduced risks of birth defects among offspring of working women.

Conclusions: Results from these analyses can be used for hypothesis generating purposes and guiding future investigations of occupational exposures and birth defects.

What this paper adds

- Several studies have found a positive association between maternal occupation or occupational exposures and various birth defects; however, many investigators group different defects together, which may introduce aetiological heterogeneity.
- This analysis is intended to give an overall picture of the relationships between maternal occupation and 45 specific birth defects to guide future analyses (hypothesis generation) and more in-depth studies of specific birth defects and specific occupations or exposures.
- The results of this study indicate that women working as janitors have a significantly increased risk of giving birth to a child with amniotic bands, anotia/microtia, anorectal atresia, anophthalmia/microphthalmia, glaucoma, bladder exstrophy or clefts.
- The results of this study indicate that women working as scientists have an increased risk of giving birth to a child with conotruncal heart defects, atrioventricular septal defect, anorectal atresia, bladder exstrophy or sacral agenesis.
- The results of this study indicate that women working as teachers have a significantly reduced risk of giving birth to a child with gastroschisis, neural tube defects, spina bifida or septal heart defects.

Several studies have found a positive association between maternal occupation or occupational exposures and various birth defects. For example, cleft defects have been associated with leather workers,[1 2] hairdressers,[3 4] housekeepers,[3] manufacturing, food production,[4] transport and communication workers.[5] Limb defects have been associated with agricultural work,[6 7] while neural tube defects have been associated with cleaners[8] and healthcare workers exposed to anaesthetics or *x* radiation.[9] Several review papers of birth defects and parental occupation have noted that many previous studies were based on small numbers resulting in reduced power to detect a moderate association between a specific occupational group and a specific defect.[10–12] To deal with this problem, many investigators group various defects together, which may introduce aetiological heterogeneity.[13]

Because of the difficulty and expense in obtaining accurate measurements of exposure, many studies depend on job title or occupation as a surrogate for exposure.[2–5] In order to assess a spectrum of maternal occupations, previous studies have developed classification schemes that collapse occupation and industry codes into 56–73 categories[14–17] based on common work activities and potential exposures. The objective of this analysis, based on data from a large national case–control study, was to examine the association between a spectrum of maternal occupations and various specific birth defects. This analysis evaluated risk by all occupational groups using a general classification based on occupation and industry, without consideration of specific chemical or physical exposures. It also includes all major birth defects.

Risk estimates were calculated for defects of nine physiological systems in each of 24 occupational groups. In addition, the association between each of the occupational groups and each of 45 specific birth defects included in the nine physiological systems was also examined. We used the term spectrum analysis to characterise this study because we analysed a large array of both occupations and birth defects in one study. This analysis is intended to give an overall picture of the relationship between maternal occupation and birth defects. The results of this analysis will be used to guide future analyses (hypothesis generation) and more in-depth studies of specific birth defects and specific occupations or exposures.

METHODS

Design and study population

The study presented here used data from the National Birth Defects Prevention Study (NBDPS) which is a large, collaborative case–control study of birth defects currently being conducted in the United States. All appropriate Institutional Review Board approvals were obtained. The goal of the NBDPS is to evaluate the association between specific birth defects and environmental and genetic factors. A total of 10 birth defects centres (Arkansas, California, Centers for Disease Control and Prevention (Atlanta), Iowa, Massachusetts, New Jersey, New York, North Carolina, Texas and Utah) have contributed data for the years 1997–2003, which are included here. The methods used by the NBDPS have been previously described.[18]

This spectrum analysis included all cases of isolated (a single major defect) and multiple (more than one unrelated major defect present in an infant) birth defects and all control births included in the NBDPS from the participating centres with estimated dates of delivery from 1 October 1997 through 31 December 2003. The NBDPS does not collect information on single gene conditions and chromosomal abnormalities. Defect cases considered complex (multiple embryologically related defects), with the exception of amniotic band sequence and heterotaxy, were excluded because they may have different aetiologies from isolated/multiple cases. All cases were identified using each centre's birth defects surveillance system and were reviewed by clinical geneticists using case-specific criteria including standardised definitions of defects, and confirmatory diagnostic procedures.[19] Controls consisted of non-malformed live-born infants, randomly selected from either birth certificates or birth hospitals. In the NBDPS, the overall ratio of cases to controls is approximately 3:1. As the same control group was used for analysis of each defect, the ratio of cases to controls will vary. However, for some centres, data on certain defects were collected for a limited number of years. For these defects, only similarly collected control data were used. Infants were excluded for the following reasons: they were adopted, they were in foster care, or their mother did not speak English or Spanish.

Data collection

A computer-assisted telephone interview with mothers was conducted in English or Spanish by trained female interviewers. Participants were enrolled using a standard procedure.[18] During the maternal interviews information was collected on maternal health status, including chronic diseases, medications used, pregnancy history and complications, maternal diet, vitamin use, caffeine, tobacco, alcohol or illicit drug use, household exposures, work history, family demographics, and water use patterns. Timing of exposures during pregnancy was recorded in the way the mother recalled best, for example by date, month or trimester. A pregnancy calendar was used to aid recall. Interviews were completed between 6 weeks and 2 years after the estimated date of delivery, an interval chosen with regard to the situation of mothers of newborns, especially those with defects, and also to allow sufficient time to ascertain all defect cases, which may take up to 2 years.

Outcomes

A total of 45 specific defects were included in the study (table 1). These defects are the major defects for which the NBDPS collects data. They were summarised into nine systems (shown in table 1): amniotic band (non-system-specific), central nervous system, ears, eyes, gastrointestinal, genitourinary, cardiovascular, musculoskeletal and orofacial. Only amniotic bands and ear defects do not contain specific defect subgroups. In the case of neural tube defects (under "Central nervous system"), limbs (under "Musculoskeletal") and clefts (under "Orofacial"), additional subgroups of specific birth defects were analysed in this study.

Exposure

A combination of occupation (job title) and industry was used to create groups. Information collected from the interview included company name, job title, what the company made or did, job duties, month/year of starting job, and month/year of ending job. A team of two occupational epidemiologists and two industrial hygienists used this information to complete occupational coding using the 2000 Standard Occupational Classification System for occupation and the 1997 North American Industry Classification System for industry. Up to six jobs held during pregnancy and the 3 months before pregnancy were recorded and coded for each woman. However, only jobs held during the critical period of fetal development, defined as 1 month prior to pregnancy through the end of the third pregnancy month, were included in these analyses. Similar occupation and industry codes were grouped into a manageable number of categories. Table 2 shows the distribution of the 24 final occupational groups among cases and controls. Women who held more than one job during the critical period were included in more than one occupational group, if appropriate.

Some of the occupational groups were broad and encompassed several subgroups, which are also listed in table 2. For example, the public servants group was made up of police, firefighters and military personnel. To restrict the analyses to a manageable number, only the major occupational groups ($n = 24$) were used. Any job held during the critical period of fetal development was considered for exposure. Mothers who did not work during the critical period were excluded. Only month and year were recorded for job start date and job end date. For calculation of the critical period, a day of the month was assigned. To be as inclusive as possible and be consistent with other NBDPS exposure assessments (ie, medications), start day was assigned as the first day of the month and end day was assigned as the last day of the month. Jobs considered to be in the critical period fall into one of four start/end date scenarios: (1) started before the critical period and ended after the critical period; (2) started before the critical period and ended during the critical period; (3) started during the critical period and ended during the critical period; and (4) started during the critical period and ended after the critical period. In the case of missing dates, as long as either the start or end date was within

Table 1 Birth defects, by system, of babies born to mothers with jobs during the critical period, who participated in the National Birth Defects Prevention Study, 1997–2003*

Defect system and defect	n (%)†
Amniotic band	100 (1.11)‡
Central nervous system	796 (8.87)‡
Cerebellar hypoplasia/Dandy-Walker	55 (6.91)
Holoprosencephaly	37 (4.65)
Hydrocephalus	152 (19.10)
Neural tube defects	562 (70.60)
Anencephaly/cranioraschischisis	151 (18.97)
Encephalocele	64 (8.04)
Spina bifida	347 (43.59)
Ears	173 (1.93)‡
Eyes	196 (2.18)‡
Cataracts	85 (43.37)
Anophthalmia/microphthalmia	72 (36.73)
Glaucoma	44 (22.45)
Gastrointestinal	823 (9.17)‡
Anorectal atresia	328 (39.85)
Biliary atresia	65 (7.90)
Colonic atresia/stenosis	10 (1.22)
Duodenal atresia/stenosis	64 (7.78)
Oesophageal atresia	261 (31.71)
Small intestinal atresia	141 (17.13)
Genitourinary	758 (8.44)‡
Hypospadias	715 (94.33)
Renal agenesis/hypoplasia	43 (5.67)
Cardiovascular	3005 (33.47)‡
APVR	88 (2.93)
AVSD	107 (3.56)
Conotruncal	638 (21.23)
Heterotaxia	52 (1.73)
LVOTO	445 (14.81)
RVOTO	433 (14.41)
Septal	1151 (38.30)
Complex	118 (3.93)
Musculoskeletal	1525 (16.99)‡
Bladder exstrophy	26 (1.70)
Cloacal exstrophy	11 (0.72)
Craniosynostosis	365 (23.93)
Diaphragmatic hernia	251 (16.46)
Gastroschisis	341 (22.36)
Limbs	386 (25.31)
Intercalary limb deficiency	23 (1.51)
Longitudinal limb deficiency	150 (9.84)
Limb deficiency, not otherwise specified	5 (0.33)
Preaxial limb deficiency	91 (5.97)
Transverse limb deficiency	218 (14.30)
Omphalocele	140 (9.18)
Sacral agenesis	20 (1.31)
Orofacial	1410 (15.71)‡
Choanal atresia	47 (3.33)
Clefts, all	1367 (96.95)
Cleft palate	477 (33.83)
Cleft lip w/wo cleft palate	890 (63.12)

APVR , anomalous pulmonary venous return; AVSD , atrioventricular septal defect; LVOTO , left ventricular outflow tract obstruction; RVOTO, right ventricular outflow tract obstruction; w/wo, with/without.

*The critical period is defined as 1 month prior to conception through the end of the third month of pregnancy. Some infants may be represented in the table more than once if they have multiple defects.

†Defect system percentages are of all cases, while percentages of specific defects refer only to the system.

‡Defect system percentages of all cases.

the critical period the job was included. If both start and end dates were missing, the job was excluded.

Statistical analysis and potential confounders

A standard set of a priori covariates was determined for use in all logistic regression models based on literature review. This set included: study centre, maternal age at delivery, maternal pre-pregnancy body mass index, maternal race/ethnicity, maternal education, parity, folic acid use, maternal smoking and maternal alcohol use. The latter three variables were specific to the critical period. Logistic regression models were run, adjusted for potential confounders, to determine the association between each of the nine birth defect systems and each of the 24 occupational groups as well as each of the 45 specific birth defects and each of the 24 occupational groups. In each analysis, all other employed women were used as the exposure reference category.

In addition to standard logistic regression, we used a Bayesian approach to logistic regression developed by Greenland[20 21] for the analysis of the 45 specific defects. This method is useful in situations such as this where multiple comparisons are made and also when there are small numbers. The Bayesian approach requires that the researcher have a "prior" belief about the effect of the exposure and covariates on the outcome before the actual analysis is performed. Prior values were set to 1, assuming no effect on the outcome, for all exposures and covariates except for maternal age greater than 35, smoking and drinking status, which had priors of 2. The prior of 2 was set for covariates known in the literature to have positive associations with the outcome. Since a variance must be specified for all priors, a conservative approach was taken and a wide variance of 1.125 was chosen in order to slightly minimise the effect of the priors on the data. In the presence of small numbers the prior distribution is not always normal, so a rescale factor of 10 was incorporated.[21] A dataset was created with the prior specifications and imported into the actual data to make an augmented dataset. In addition, an indicator variable was created in the augmented dataset to indicate whether a record was from the prior data or the actual data. The Bayesian analysis was conducted by running logistic regression with the augmented dataset.

RESULTS

The overall response rate for the NBDPS was 65.6% (69% for cases and 65% for controls). Of those who responded, approximately 72% of case mothers and 72% of control mothers were employed in a wide variety of occupations and industries. Of those mothers employed during the critical period, most (88.9%) held only one job during the critical period, while 10.1% had two jobs, 0.9% had three jobs, 0.1% had four jobs, and less than 0.1% had five or six jobs. After condensing these various occupations into meaningful occupational groups, we found that the largest group, for both cases and controls, was administrative support workers (over 20%). Other large groups making up roughly 12–13% of both cases and controls were sales workers, food industry workers (mostly food service workers) and healthcare workers (mostly nurses). Ten of the 24 groups were extremely small, each containing approximately 1% or less of the total cases and controls and included artists, public servants, landscapers, construction workers, metal workers/welders, dry cleaners, chemical/semiconductor workers, textile/paper workers, electronic equipment operators and manufacturing/transportation workers.

Table 3 shows the demographic characteristics of cases (n = 8977) and controls (n = 3383). Case mothers were more

Table 2 Occupational groups of mothers with jobs during the critical period who participated in the National Birth Defects Prevention Study, 1997–2003*

Occupational group	Cases (n = 8977) n (%)†	Controls (n = 3383) n (%)†
Math and computer scientists	162 (1.80)‡	59 (1.74)‡
Scientists	172 (1.92)‡	60 (1.77)‡
Surveyors, geologists, geoscientists	0 (0.00)	4 (6.67)
Engineers, science technicians	36 (20.93)	8 (13.33)
Biological scientists	94 (54.65)	37 (61.67)
Chemical scientists and pharmacists	42 (24.42)	11 (18.33)
Artists	54 (0.60)‡	14 (0.41)‡
Artists	9 (16.67)	4 (26.67)
Photographers, photo processors	24 (44.44)	5 (33.33)
Printers	21 (38.89)	5 (33.33)
Healthcare workers	1093 (12.18)‡	441 (13.04)‡
Health care practitioners	58 (5.31)	30 (6.80)
Dentists, dental assistants	64 (5.86)	33 (7.48)
Nurses, therapists, health technicians	972 (88.93)	378 (85.71)
Public servants	63 (0.70)‡	26 (0.77)‡
Police, guards	54 (85.71)	20 (76.92)
Firefighters	0 (0.00)	1 (3.85)
Armed forces	9 (14.29)	5 (19.23)
Food servers/processors	1124 (12.52)‡	411 (12.15)‡
Food service workers	999 (88.88)	364 (88.56)
Food processing workers	133 (11.83)	49 (11.92)
Janitors, cleaners	350 (3.90)‡	104 (3.07)‡
Personal service, athletes	420 (4.68)‡	164 (4.85)‡
Entertainers, athletes	67 (15.95)	34 (20.73)
Personal service workers	354 (84.29)	130 (79.27)
Hairdressers and cosmetologists	143 (1.59)‡	45 (1.33)‡
Office other	954 (10.63)‡	353 (10.43)‡
Business and financial specialists	449 (47.06)	159 (45.04)
Architects, drafters, designers	75 (7.86)	21 (5.95)
Legal and social service workers	335 (35.12)	132 (37.39)
Media and communication workers	61 (6.39)	22 (6.23)
Messengers	39 (4.09)	19 (5.38)
Managers, administrators	713 (7.94)‡	302 (8.93)‡
Teachers	720 (8.02)‡	342 (10.11)‡
Sales workers	1183 (13.18)‡	436 (12.89)‡
Administrative support	2001 (22.29)‡	735 (21.73)‡
Farm workers	175 (1.95)‡	57 (1.68)‡
Landscapers	23 (0.26)‡	3 (0.09)‡
Landscapers, groundskeepers	10 (43.48)	0 (0.00)
Forestry and logging workers	3 (13.04)	0 (0.00)
Sawmill workers	10 (43.48)	3 (100.00)
Construction workers	100 (1.11)‡	33 (0.98)‡
Construction workers	8 (8.00)	5 (15.15)
Carpenters, wood workers	14 (14.00)	6 (18.18)
Electricians, electrical and electronics workers	61 (61.00)	16 (48.48)
Stone, glass and concrete workers	4 (4.00)	3 (9.09)
Painters	14 (14.00)	3 (9.09)
Metal workers/welders	29 (0.32)‡	5 (0.15)‡
Foundry and smelter workers	3 (10.34)	0 (0.00)
Sheet metal, iron and other metal workers	22 (75.86)	2 (40.00)
Welders, cutters	4 (13.79)	3 (60.00)
Dry cleaners	45 (0.50)‡	10 (0.30)‡
Chemical/semiconductor workers	76 (0.85)‡	17 (0.50)‡
Chemical workers, NEC	73 (96.05)	14 (82.35)
Semiconductor processors	3 (3.95)	3 (17.65)
Textile, paper workers	77 (0.86)‡	30 (0.89)‡
Textile workers	66 (85.71)	25 (83.33)
Paper workers	12 (15.58)	5 (16.67)
Shippers, operators	175 (1.95)‡	78 (2.31)‡
Shippers	163 (93.14)	69 (88.46)
Plant and system operators	6 (3.43)	3 (3.85)

Continued

Table 2 Continued

Occupational group	Cases (n = 8977) n (%)†	Controls (n = 3383) n (%)†
Material moving equipment operators	6 (3.43)	6 (7.69)
Electronic equipment operators	107 (1.19)‡	36 (1.06)‡
Manufacturing, transportation workers	120 (1.34)‡	43 (1.27)‡
Vehicle manufacturing	20 (16.67)	6 (13.95)
Vehicle mechanics	3 (2.50)	2 (4.65)
Mechanics, NEC	19 (15.83)	6 (13.95)
Motor vehicle operators	55 (45.83)	21 (48.84)
Aircraft operators, air crew	16 (13.33)	7 (16.28)
Rail transportation workers	3 (2.50)	0 (0.00)
Water transportation workers	1 (0.83)	1 (2.33)
Transportation workers, NEC	2 (1.67)	0 (0.00)
Service station attendants	2 (1.67)	0 (0.00)

NEC, not elsewhere classified.
*The critical period is defined as 1 month prior to conception through the end of the third month of pregnancy.
†Percentages may not add to 100% because of multiple jobs in some instances. Percentage of main occupations (n = 24) is of total cases or controls and percentage for each subgroup is of the parent group.
‡Percentage of total cases or controls.

likely to be over 35, obese, nulliparous, have pre-pregnancy diabetes, and smoke, while control mothers were more likely to be college educated.

Table 4 shows adjusted odds ratios from the standard logistic regression for the risk of birth defects (grouped into nine systems) among 24 occupational groups. Not all combinations could be analysed due to small sample size. Janitors and cleaners had elevated risks for four birth defect systems (amniotic band, central nervous system, ear and eye). Teachers showed reduced risks for two categories of birth defects (central nervous system and heart).

Table 5 is a summary of the standard logistic regression analysis and the corresponding Bayesian results of the 24 occupational groups and the 45 specific birth defects included in the study. Only results that were statistically significant ($p<0.05$) in at least one of the analyses are presented because of the large number of comparisons made.

Several occupational groups showed a risk for multiple defects, including electronic equipment operators, janitors and scientists, among others. For instance, janitors had significant increased risks not only for amniotic bands and ear defects (anotia/microtia) as previously mentioned, but also for five other birth defects including two eye defects, one musculoskeletal defect, one gastrointestinal defect and clefts. All but amniotic bands and bladder exstrophy (musculoskeletal system) remained significant in the Bayesian analysis. Scientists had an increased risk for five specific defects including two heart defects, two musculoskeletal defects and one gastrointestinal defect. All but sacral agenesis (musculoskeletal system) remained significant in the Bayesian analysis. Conversely, teachers had significantly reduced risks for four specific defects, all of which remained significant in the Bayesian analysis. Interestingly, although healthcare workers had reduced risks for three specific defects, they also had an increased risk for two specific defects, all of which remained significant in the Bayesian analysis. Other occupational groups with a mix of positive and negative results in the standard analysis were administrative support workers, food workers and other office workers. Only food workers and other office workers showed this mix in the Bayesian analysis.

A total of 17 (16 positive and one negative) results were no longer significant in the Bayesian analysis. This was not unexpected as the Bayesian analysis considers multiple comparisons and is stricter than the standard method of logistic regression that was used for the presented analysis. Most of the results that were significant in the standard analysis and not significant in the Bayesian analysis were those performed on groups with very small numbers of exposed cases (13 of 17 comparisons had three or fewer exposed cases); the remaining four comparisons were of borderline significance in the standard analysis.

DISCUSSION

Using a large population-based case–control study, we were able to analyse a spectrum of occupations and 45 specific birth defects for hypothesis generating purposes. Using standard logistic regression, these analyses resulted in 42 (26 for Bayesian) significantly elevated risks of birth defects in the offspring of working mothers. The job positively associated with the largest number of birth defects was that of janitors/cleaners. Cleaners and housekeepers have previously been positively associated with neural tube defects (NTDs), spina bifida and oral clefts in three separate studies.[3 8 23] Our study also found a positive association between cleaners and oral clefts. In addition, although the association was not significant, we also observed an elevated risk for NTDs and more specifically, spina bifida (data not shown). At the system level, central nervous system defects (which include, NTDs and spina bifida) were positively associated with cleaners.

In addition to the positive associations discussed above, we also found several reduced risks. Using standard logistic regression, we found 12 (11 for Bayesian) significantly reduced risks of birth defects among the offspring of working women. The job negatively associated with the largest number of birth defects was teaching. Teachers have not been commonly studied in occupational studies of birth defects, likely due to their lower perceived risk. However, two studies of clefts looked at teachers as a group; one study found a reduced effect similar to our cleft results[23] and one study found non-significant results very close to the null for various cleft subgroups (OR 1.1–1.3).[4]

Due to its large size and breadth of interview-based information, including data on specific potential confounders, the NBDPS is a good study to use to conduct a spectrum analysis. This study has included a large number of women in order to study 45 specific birth defects. Most of the women in the NBDPS were workers in a variety of occupations. With the

Table 3 Demographic characteristics of women with jobs during the critical period who participated in the National Births Defects Prevention Study, 1997–2003*

Covariates	Cases (n = 8977) n (%)	Controls (n = 3383) n (%)	OR (95% CI)
Maternal age at delivery			
<20 years	701 (7.81)	244 (7.21)	1.11 (0.96 to 1.30)
20–34 years	6814 (75.91)	2641 (78.07)	1.00 (reference)
35+	1462 (16.29)	498 (14.72)	1.14 (1.02 to 1.27)
Maternal BMI†			
Underweight (<18.5)	471 (5.25)	173 (5.11)	1.09 (0.90 to 1.30)
Normal weight (⩾18.5<25)	4731 (52.70)	1886 (55.75)	1.00 (reference)
Overweight (⩾25<30)	2000 (22.28)	738 (21.81)	1.08 (0.98 to 1.19)
Obese (⩾30)	1587 (17.68)	522 (15.43)	1.21 (1.08 to 1.36)
Maternal education			
<High school	972 (10.83)	324 (9.58)	1.01 (0.87 to 1.17)
High school	2361 (26.30)	795 (23.50)	1.00 (reference)
College	5638 (62.80)	2260 (66.80)	0.84 (0.76 to 0.92)
Maternal race/ethnicity			
White	5914 (65.88)	2237 (66.12)	1.00 (reference)
Black	976 (10.87)	409 (12.09)	0.90 (0.80 to 1.02)
Hispanic	1603 (17.86)	566 (16.73)	1.07 (0.96 to 1.19)
Other	471 (5.25)	164 (4.85)	1.09 (0.90 to 1.31)
Parity			
0	4379 (48.78)	1515 (44.78)	1.18 (1.09 to 1.27)
1+	4594 (51.18)	1867 (55.19)	1.00 (reference)
Site location			
Arkansas	1227 (13.67)	400 (11.82)	1.00 (reference)
California	921 (10.26)	378 (11.17)	0.79 (0.67 to 0.94)
Iowa	1009 (11.24)	466 (13.77)	0.71 (0.60 to 0.83)
Massachusetts	1366 (15.22)	487 (14.40)	0.91 (0.78 to 1.07)
New Jersey	1143 (12.73)	388 (11.47)	0.96 (0.82 to 1.13)
New York	743 (8.28)	328 (9.70)	0.74 (0.62 to 0.88)
Texas	1046 (11.65)	356 (10.52)	0.96 (0.81 to 1.13)
CDC (Atlanta)	1166 (12.99)	390 (11.53)	0.97 (0.83 to 1.14)
North Carolina	148 (1.65)	104 (3.07)	0.46 (0.35 to 0.61)
Utah	208 (2.32)	86 (2.54)	0.79 (0.60 to 1.04)
Pre-pregnancy diabetes			
Yes	179 (1.99)	16 (0.47)	4.28 (2.56 to 7.15)
No	8787 (97.88)	3362 (99.38)	1.00 (reference)
Folic acid			
Yes	4900 (54.58)	1850 (54.69)	1.00 (0.92 to 1.08)
No	4077 (45.42)	1533 (45.31)	1.00 (reference)
Maternal drinking			
Yes	3797 (42.30)	1463 (43.25)	0.96 (0.89 to 1.04)
No	5140 (57.26)	1909 (56.43)	1.00 (reference)
Maternal smoking			
Yes	1983 (22.09)	682 (20.16)	1.12 (1.02 to 1.24)
No	6992 (77.89)	2701 (79.84)	1.00 (reference)

BMI, body mass index; CDC, Centers for Disease Control and Prevention.
*The critical period is defined as 1 month prior to conception through the end of the third month of pregnancy.
†BMI cutpoints established by the National Institutes of Health.[22]

help of industrial hygienists we were able to create meaningful occupational groupings with sufficient size to conduct analyses. These groupings also tend to group workers based on other attributes such as education and socio-economic status. Extensive information was collected on potential confounders, such as socio-demographic factors and maternal behaviours during pregnancy. This overall assessment of the association between various occupations and all birth defects is useful as a hypothesis generating tool. A future paper will look at teachers, janitors and healthcare workers in more detail by breaking these broad groups down into more specific occupations and considering hours worked. Also, this spectrum analysis provides guidance on future analyses of specific defects and specific maternal occupations that can be performed with NBDPS data. Although this analysis was adjusted for several potential confounders, future studies looking at specific outcomes and exposures should include other confounders applicable to those analyses, such as medication use, diet and home exposures.

This analysis used job title to create occupational groups. The analysis did not consider hours/days worked or possible chemical exposures. A separate project being conducted within the NBDPS is working on a more detailed exposure assessment for pesticides, solvents and metals using this information.

We carried out a total of 1080 different comparisons for this analysis (24 occupational groups×45 specific defects). With so many comparisons being made, one would expect a number (up

Table 4 Adjusted odds ratios and 95% confidence intervals for the association between occupational groups and birth defect systems among the children of mothers with jobs during the critical period who participated in the National Birth Defects Prevention Study, 1997–2003*

	Amniotic band		Central nervous system		Ear		Eye		Gastrointestinal	
Occupational group	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**
Computer scientists	0	–	8	0.69 (0.32 to 1.47)	2	0.58 (0.13 to 2.58)	2	1.23 (0.42 to 3.59)	13	0.96 (0.53 to 1.76)
Scientists	2	0.93 (0.22 to 4.03)	14	1.37 (0.79 to 2.39)	2	0.84 (0.20 to 3.57)	2	0.63 (0.19 to 2.06)	18	1.30 (0.76 to 2.24)
Artists	1	2.44 (0.31 to 19.29)	6	2.45 (0.97 to 6.16)	1	2.48 (0.51 to 12.03)	0	1.88 (0.22 to 15.86)	4	1.12 (0.36 to 3.46)
Healthcare workers	9	0.87 (0.44 to 1.71)	104	1.20 (0.96 to 1.51)	17	0.95 (0.57 to 1.58)	23	1.17 (0.76 to 1.81)	106	1.13 (0.90 to 1.42)
Public servants	0	–	5	1.26 (0.56 to 2.86)	3	2.57 (0.74 to 8.89)	2	3.32 (1.06 to 10.40)	7	1.26 (0.56 to 2.82)
Food servers/processors	14	1.39 (0.79 to 2.46)	103	1.18 (0.93 to 1.49)	16	0.78 (0.47 to 1.30)	15	0.84 (0.50 to 1.39)	74	0.83 (0.64 to 1.08)
Janitors/cleaners	6	2.41 (1.04 to 5.59)	35	1.49 (1.02 to 2.19)	12	2.67 (1.47 to 4.85)	11	3.27 (1.78 to 5.99)	31	1.48 (0.99 to 2.20)
Personal service/athletes	7	1.84 (0.88 to 3.83)	35	1.07 (0.75 to 1.52)	5	0.70 (0.28 to 1.75)	7	0.93 (0.46 to 1.92)	30	1.05 (0.73 to 1.51)
Hairdressers	1	0.57 (0.07 to 4.48)	8	1.06 (0.54 to 2.08)	4	2.24 (0.77 to 6.51)	0	–	10	0.97 (0.48 to 1.95)
Office, other†	12	1.25 (0.64 to 2.43)	63	0.96 (0.72 to 1.27)	5	0.31 (0.12 to 0.77)	20	1.29 (0.80 to 2.07)	83	1.11 (0.86 to 1.44)
Managers	1	0.39 (0.12 to 1.26)	49	0.91 (0.67 to 1.24)	18	1.75 (1.03 to 2.96)	18	0.83 (0.48 to 1.44)	67	0.97 (0.74 to 1.29)
Teachers	6	0.70 (0.30 to 1.64)	46	0.67 (0.49 to 0.92)	14	1.04 (0.58 to 1.88)	16	0.73 (0.42 to 1.25)	63	0.88 (0.67 to 1.16)
Sales workers	10	1.00 (0.56 to 1.77)	88	1.03 (0.82 to 1.29)	20	1.29 (0.84 to 1.99)	18	1.01 (0.64 to 1.59)	83	0.96 (0.76 to 1.22)
Administrative support	23	1.22 (0.76 to 1.97)	147	0.97 (0.80 to 1.17)	27	0.76 (0.50 to 1.17)	29	0.86 (0.58 to 1.27)	157	1.00 (0.82 to 1.21)
Farm workers	2	1.22 (0.26 to 5.77)	27	1.43 (0.86 to 2.36)	7	2.03 (0.84 to 4.91)	3	1.11 (0.31 to 4.02)	12	1.01 (0.55 to 1.88)
Landscapers	0	–	0	1.11 (0.11 to 10.84)	2	–	1	6.12 (0.73 to 50.94)	3	5.23 (1.14 to 23.86)
Construction workers	1	1.15 (0.15 to 8.84)	6	0.99 (0.47 to 2.10)	1	0.51 (0.07 to 3.93)	2	1.11 (0.24 to 5.04)	5	0.73 (0.30 to 1.77)
Metal workers/welders	2	22.05 (3.66 to 132.73)	3	1.87 (0.44 to 8.04)	0	–	0	–	3	3.22 (0.90 to 11.48)
Dry cleaners	0	–	2	0.68 (0.15 to 3.19)	1	0.84 (0.10 to 7.09)	0	1.14 (0.13 to 9.92)	3	1.65 (0.54 to 5.00)
Chemical/semiconductor workers	1	2.28 (0.28 to 18.37)	5	1.86 (0.78 to 4.43)	3	1.88 (0.50 to 7.10)	2	2.27 (0.60 to 8.60)	6	1.56 (0.62 to 3.89)
Textile/paper workers	0	–	5	0.65 (0.27 to 1.61)	1	0.46 (0.06 to 3.51)	2	0.97 (0.22 to 4.34)	4	0.78 (0.32 to 1.91)
Shippers, operators	1	0.50 (0.07 to 3.76)	11	0.68 (0.38 to 1.22)	6	1.09 (0.45 to 2.65)	3	0.69 (0.24 to 1.97)	22	1.17 (0.72 to 1.90)
Electronic equipment operators	1	2.20 (0.62 to 7.72)	13	1.87 (1.04 to 3.36)	1	0.93 (0.21 to 4.14)	2	0.88 (0.19 to 3.97)	6	0.65 (0.27 to 1.57)
Manufacturing/transportation workers	0	–	10	0.92 (0.47 to 1.81)	5	3.03 (1.19 to 7.70)	2	0.86 (0.20 to 3.72)	12	1.14 (0.59 to 2.20)

	Genitourinary		Cardiovascular		Musculoskeletal		Orofacial	
Occupational group	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**	**n**	**OR (95% CI)**
Computer scientists	25	1.26 (0.69 to 2.29)	49	1.00 (0.68 to 1.47)	25	1.12 (0.70 to 1.81)	29	1.28 (0.82 to 2.00)
Scientists	15	1.56 (0.76 to 3.21)	56	1.13 (0.78 to 1.63)	24	1.01 (0.63 to 1.61)	20	0.93 (0.56 to 1.55)
Artists	3	0.54 (0.13 to 2.24)	15	1.27 (0.61 to 2.64)	5	0.99 (0.39 to 2.49)	8	1.58 (0.66 to 3.76)
Healthcare workers	88	0.89 (0.67 to 1.18)	339	0.88 (0.75 to 1.02)	178	1.03 (0.85 to 1.24)	140	0.82 (0.67 to 1.00)
Public servants	7	1.42 (0.54 to 3.77)	17	0.78 (0.42 to 1.45)	9	0.92 (0.44 to 1.94)	7	0.84 (0.39 to 1.81)
Food servers/processors	49	0.81 (0.57 to 1.14)	291	0.95 (0.80 to 1.12)	187	1.06 (0.88 to 1.29)	162	0.96 (0.78 to 1.17)
Janitors/cleaners	10	0.56 (0.28 to 1.11)	84	1.16 (0.87 to 1.54)	40	1.19 (0.85 to 1.67)	48	1.40 (0.99 to 1.98)
Personal service/athletes	26	0.91 (0.58 to 1.44)	107	0.89 (0.70 to 1.13)	59	1.07 (0.80 to 1.42)	54	0.98 (0.73 to 1.32)
Hairdressers	12	1.33 (0.63 to 2.84)	39	1.12 (0.74 to 1.72)	23	1.15 (0.69 to 1.92)	24	1.49 (0.90 to 2.45)
Office, other†	110	1.20 (0.91 to 1.59)	285	0.98 (0.82 to 1.15)	144	1.05 (0.85 to 1.29)	155	1.22 (0.99 to 1.50)
Managers	83	0.93 (0.68 to 1.26)	253	1.00 (0.84 to 1.20)	83	0.67 (0.52 to 0.87)	93	0.79 (0.62 to 1.01)
Teachers	64	0.81 (0.59 to 1.13)	222	0.82 (0.68 to 0.98)	98	0.80 (0.64 to 1.01)	97	0.81 (0.64 to 1.03)
Sales workers	78	1.24 (0.92 to 1.66)	354	1.09 (0.94 to 1.27)	179	0.97 (0.81 to 1.17)	137	0.86 (0.70 to 1.04)
Administrative support	149	0.97 (0.77 to 1.23)	618	1.01 (0.89 to 1.14)	345	1.22 (1.05 to 1.41)	293	1.12 (0.96 to 1.30)
Farm workers	5	1.28 (0.49 to 3.38)	42	1.14 (0.75 to 1.73)	28	1.01 (0.62 to 1.62)	27	1.21 (0.75 to 1.95)
Landscapers	0	–	8	1.71 (0.41 to 7.18)	1	0.51 (0.05 to 5.08)	1	0.80 (0.08 to 7.75)
Construction workers	8	1.26 (0.52 to 3.08)	30	1.01 (0.61 to 1.67)	13	0.94 (0.50 to 1.75)	20	1.34 (0.77 to 2.35)
Metal workers/welders	0	–	9	1.74 (0.59 to 5.18)	3	1.17 (0.27 to 4.96)	4	2.31 (0.66 to 8.13)
Dry cleaners	4	6.90 (0.75 to 63.63)	14	1.79 (0.80 to 3.97)	5	1.10 (0.37 to 3.28)	7	1.77 (0.71 to 4.44)
Chemical/semiconductor workers	4	1.26 (0.38 to 4.20)	24	1.73 (0.92 to 3.27)	10	1.15 (0.50 to 2.68)	7	1.55 (0.70 to 3.41)
Textile/paper workers	0	0.12 (0.01 to 1.13)	28	0.97 (0.57 to 1.66)	11	1.03 (0.53 to 2.02)	16	1.29 (0.69 to 2.42)
Shippers, operators	9	0.68 (0.32 to 1.44)	57	0.88 (0.62 to 1.24)	25	0.78 (0.50 to 1.23)	25	0.86 (0.55 to 1.33)
Electronic equipment operators	2	0.45 (0.12 to 1.69)	27	1.08 (0.67 to 1.73)	16	1.21 (0.69 to 2.10)	15	1.20 (0.67 to 2.13)
Manufacturing/transportation workers	7	0.81 (0.34 to 1.94)	33	0.95 (0.61 to 1.48)	15	1.01 (0.59 to 1.72)	20	1.12 (0.64 to 1.94)

*Models are adjusted for the following: study centre, folic acid use, maternal age at delivery, maternal pre-pregnancy body mass index, maternal race/ethnicity, maternal education, parity, maternal smoking and maternal alcohol use during the first trimester. The critical period is defined as 1 month prior to conception through the end of the third month of pregnancy. Some infants may be represented in the table more than once if they have multiple defects.

†Includes business/financial specialists, architects/drafters/designers, legal/social workers, media/communication workers and messengers.

Table 5 Adjusted odds ratios and 95% confidence intervals for birth defects associated with occupational groups of women with jobs during the critical period who participated in the National Births Defects Prevention Study, 1997–2003*

Occupational group	Birth defect	Exposed cases	Standard logistic regression, adjusted OR (95% CI)	Bayesian approach to logistic regression, adjusted OR (95% CI)
Administrative support	Craniosynostosis	101	1.35 (1.05 to 1.74)	1.35 (1.06 to 1.74)
	Encephalocele	7	0.45 (0.20 to 0.99)	0.50 (0.24 to 1.02)
Artists	APVR	2	5.13 (1.10 to 24.00)	2.64 (0.64 to 10.97)
	Intercalary limb deficiency	1	10.62 (1.10 to 102.85)	2.31 (0.37 to 14.64)
Chemical/semiconductor	Cataract	2	6.25 (1.18 to 33.14)	2.80 (0.65 to 12.15)
workers	Neural tube defects	8	2.90 (1.21 to 6.99)	2.44 (1.07 to 5.57)
Dry cleaners	Oesophageal atresia	4	5.29 (1.57 to 17.85)	3.45 (1.12 to 10.60)
	Intercalary limb deficiency	1	11.84 (1.20 to 116.56)	2.38 (0.37 to 15.38)
Electronic equipment	Encephalocele	5	6.89 (2.40 to 19.78)	4.62 (1.67 to 12.76)
operators	LVOTO	11	2.70 (1.33 to 5.46)	2.41 (1.22 to 4.75)
	Neural tube defects	14	2.29 (1.21 to 4.37)	2.13 (1.14 to 3.96)
Farm workers	Encephalocele	3	4.26 (1.09 to 16.61)	2.23 (0.68 to 7.37)
Food servers/processors	APVR	20	2.19 (1.25 to 3.83)	2.04 (1.19 to 3.51)
	LVOTO	36	0.65 (0.45 to 0.95)	0.66 (0.46 to 0.95)
	Preaxial limb deficiency	21	1.77 (1.01 to 3.09)	1.69 (0.98 to 2.90)
Hairdressers	Gastroschisis	10	2.64 (1.24 to 5.59)	2.35 (1.14 to 4.84)
Healthcare workers	Conotruncal defects	61	0.73 (0.55 to 0.98)	0.74 (0.55 to 0.98)
	Hydrocephalus	36	2.31 (1.54 to 3.46)	2.23 (1.50 to 3.33)
	Oral clefts	141	0.80 (0.65 to 0.98)	0.80 (0.65 to 0.98)
	RVOTO	43	0.68 (0.49 to 0.96)	0.69 (0.49 to 0.96)
	Transverse limb deficiency	38	1.55 (1.07 to 2.26)	1.52 (1.05 to 2.20)
Metal workers/welders	Amniotic band	2	22.05 (3.66 to 132.73)	4.50 (0.88 to 22.98)
	Colonic atresia/stenosis	1	310.93 (9.30 to 10 399.48)	2.94 (0.38 to 22.53)
Janitors, cleaners	Amniotic band	7	2.41 (1.04 to 5.59)	2.07 (0.93 to 4.61)
	Anophthalmia/microphthalmia	7	2.80 (1.19 to 6.59)	2.48 (1.10 to 5.61)
	Anorectal atresia	18	1.82 (1.06 to 3.10)	1.74 (1.03 to 2.94)
	Anotia/microtia	16	2.67 (1.47 to 4.85)	2.47 (1.38 to 4.42)
	Bladder exstrophy	3	5.46 (1.45 to 20.48)	3.07 (0.90 to 10.44)
	Glaucoma	6	6.93 (2.46 to 19.54)	4.78 (1.82 to 12.54)
	Oral clefts	59	1.43 (1.01 to 2.02)	1.41 (1.01 to 1.99)
Landscapers	Anophthalmia/microphthalmia	1	10.83 (1.02 to 114.49)	2.28 (0.36 to 14.44)
	Heterotaxia	1	26.40 (2.35 to 296.15)	2.61 (0.38 to 18.04)
	Intestinal atresia	3	25.24 (4.52 to 140.85)	6.30 (1.49 to 26.70)
Managers	Anotia/microtia	19	1.75 (1.03 to 2.96)	1.67 (1.00 to 2.79)
	Gastroschisis	8	0.44 (0.21 to 0.93)	0.48 (0.25 to 0.94)
Manufacturing/transportation workers	Anotia/microtia	6	3.03 (1.19 to 7.70)	2.51 (1.03 to 6.09)
Office, other†	Anotia/microtia	5	0.31 (0.12 to 0.77)	0.37 (0.17 to 0.81)
	Cataract	15	1.91 (1.04 to 3.50)	1.81 (1.01 to 3.26)
	Diaphragmatic hernia	38	1.64 (1.12 to 2.39)	1.61 (1.11 to 2.33)
Personal service/athletes	Cleft palate	33	1.54 (1.03 to 2.28)	1.52 (1.03 to 2.24)
	Duodenal atresia/stenosis	7	2.68 (1.18 to 6.08)	2.27 (1.03 to 4.99)
	Gastroschisis	33	2.02 (1.31 to 3.13)	1.97 (1.29 to 3.03)
Public servants	Preaxial limb deficiency	3	4.14 (1.19 to 14.39)	2.76 (0.84 to 9.04)
Sales workers	Cleft palate	46	0.71 (0.51 to 0.99)	0.72 (0.52 to 0.99)
Scientists	Anorectal atresia	12	2.38 (1.24 to 4.55)	2.19 (1.16 to 4.11)
	AVSD	5	3.34 (1.28 to 8.73)	2.62 (1.04 to 6.61)
	Bladder exstrophy	3	8.01 (2.16 to 29.66)	4.01 (1.13 to 14.18)
	Conotruncal defects	20	1.91 (1.13 to 3.22)	1.83 (1.10 to 3.05)
	Sacral agenesis	1	11.01 (1.16 to 104.48)	2.06 (0.35 to 12.13)
Teachers	Gastroschisis	7	0.31 (0.14 to 0.68)	0.36 (0.18 to 0.72)
	Neural tube defects	34	0.60 (0.41 to 0.87)	0.61 (0.42 to 0.88)
	Septal defects	85	0.76 (0.58 to 0.99)	0.76 (0.59 to 0.98)
	Spina bifida	17	0.47 (0.28 to 0.78)	0.49 (0.30 to 0.80)
Textile/paper workers	AVSD	3	4.23 (1.20 to 14.84)	2.65 (0.81 to 8.65)

APVR, anomalous pulmonary venous return; AVSD, atrioventricular septal defect; LVOTO, left ventricular outflow tract obstruction; RVOTO, right ventricular outflow tract obstruction.
*The critical period is defined as 1 month prior to conception through the end of the third month of pregnancy. Models are adjusted for the following: study centre, folic acid use, maternal age at delivery, maternal pre-pregnancy body mass index, maternal race/ethnicity, maternal education, parity, maternal smoking and maternal alcohol use during the first trimester. Only results that are statistically significant using either the standard or Bayesian models are presented. Some infants may be represented in the table more than once if they have multiple defects.
†Includes business/financial specialists, architects/drafters/designers, legal/social workers, media/communication workers and messengers.

to 5%) of significant results to occur simply by chance. In addition, some estimates provided in table 5 are unstable due to the small number of exposed cases, such as those for artists, farm workers, metal workers/welders, landscapers, public servants and textile/paper workers. These point estimates tended to be larger with standard logistic regression. The Bayesian method used is useful when dealing with both multiple comparisons and small numbers. The Bayesian method can pull or shrink coefficient estimates toward prior values or the null, thus limiting the occurrence of type 1 errors. Stable coefficients experience very little pull, while unstable estimates are more strongly pulled toward prior values. The degree of adjustment is controlled by specifying the prior variance to achieve more precise and reasonable confidence intervals than in traditional methods. By using conservative prior estimates in our Bayesian analysis, we found that the results of analyses with small numbers of exposed cases or of borderline significance were the results that became non-significant when applying the Bayesian analysis. Therefore, the significant Bayesian results seem to be stable and likely have less type 1 error, as the method suggests. Thus, these results seem less likely to be due to chance alone. Although the results using standard logistic regression may be useful for hypothesis generating, which is the main purpose of our analysis, the results from the Bayesian analysis are likely more precise. Given the novelty of the Bayesian approach, we felt that presentation of both standard logistic regression and Bayesian logistic regression results was warranted.

Because this was a spectrum paper, the analysis was less detailed than would have been ideal. For example, in order to have a more manageable number of analyses we chose to use 24 occupational groups, each analysed with our 45 specific defects. Creating just 24 occupational groups could have introduced some misclassification bias. However, we began our analysis with 59 occupational groups, and those results did not differ greatly from the results presented here. The major advantage of using the 24 groups for this spectrum paper is that the results presented are more easily described and understood. Similar occupational spectrum studies have used up to 73 different occupational groups but were only looking at one outcome.[15] Other occupational studies have grouped all birth defects together.[1 11] For our study, industrial hygienists were consulted to develop the 24 groups. Some groups are more homogenous than others and were unchanged from the more expanded analysis (eg, dry cleaners and sales workers). However, other groups may be more mixed (eg, manufacturing/transportation workers and construction workers). These groups tended to aggregate job titles which very few women held. Therefore, our only chance to examine them, even in such a large study, was to group them. Groups that were large and where strong or multiple effects were seen (such as healthcare workers, janitors and teachers) will be followed up in subsequent in-depth analyses. Finally, although we presented results for nine physiological groups that were created by clinicians expert in birth defects, there may be some heterogeneity in these groups. Thus, the results for the 45 specific birth defects may be more useful.

Some misclassification may result from our assignments of job start and end day when calculating the critical period. We felt that choosing the first day of the start month and the last day of the end month would be most inclusive. Furthermore, this strategy was consistent with the method used for medication use in the NBDPS study. Lastly, the same strategy was applied to both cases and controls. Therefore, any potential misclassification should be non-differential with respect to the outcomes.

Because the overall response rate for the study was 66%, selection bias is a potential concern. As information on non-responders is not available, it is not possible to compare responders and non-responders to assess this potential bias related to response rate. Also, in any retrospective study, recall bias is a concern. In this study, women who frequently changed jobs would be of particular concern. Women were asked between 6 and 23 months after the birth of their child to report on jobs held during their entire pregnancy and just before pregnancy. A pregnancy calendar was used to aid recall. Approximately 1% of our population (1.1% of cases and 0.9% of controls) reported three or more jobs during the critical period. Therefore, recall bias may be less likely. In addition, this analysis is based on job title and description rather than questions about specific chemical or physical exposures. A general question about job title is less likely to be affected by the mother's knowledge of her child's case/control status than specific questions about chemical or physical exposures. Finally, although this analysis adjusted for education, race and ethnicity among other covariates, this may not adequately control for the complex mixture of factors related to socio-economic status.

Conclusion

This paper presents results from analyses on a spectrum of occupations and birth defects for hypothesis generating purposes and presents information useful for guiding future investigations of occupational exposures and birth defects. Several occupations have been found to be positively associated with one or more specific birth defects in a sample of working women, including those of janitors/cleaners, scientists and electronic equipment operators. In addition, several other occupations were found to be negatively associated with one or more birth defects including those of teachers and healthcare workers.

Acknowledgements: The authors acknowledge Dr Kimberly Campbell and other National Birth Defects Prevention Study investigators for their valuable contributions. The findings and conclusions of this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

Funding: This research was supported by a cooperative agreement from the Centers for Disease Control and Prevention (U50CCU213244).

Competing interests: None.

Ethics approval: All appropriate Institutional Review Board approvals were obtained.

Provenance and peer review: Not commissioned; externally peer reviewed.

REFERENCES

1. **Bianchi F,** Cianciulli D, Pierini A, *et al*. Congenital malformations and maternal occupation: a registry based case-control study. *Occup Environ Med* 1997;**54**:223–8.
2. **Garcia AM,** Fletcher T. Maternal occupation in the leather industry and selected congenital malformations. *Occup Environ Med* 1998;**55**:284–6.
3. **Lorente C,** Cordier S, Bergeret A, *et al*. Maternal occupational risk factors for oral clefts. Occupational Exposure and Congenital Malformation Working Group. *Scand J Work Environ Health* 2000;**26**:137–45.
4. **Nguyen RHN,** Wilcox AJ, Moen BE, *et al*. Parent's occupation and isolated orofacial clefts in Norway: a population-based case-control study. *Ann Epidemiol* 2007;**17**:763–71.
5. **Hemminki K,** Mutanen P, Saloniemi I, *et al*. Congenital malformations and maternal occupation in Finland: multivariate analysis. *J Epidemiol Community Health* 1981;**35**:5–10.
6. **Engel LS,** O'Meara ES, Schwartz SM. Maternal occupation in agriculture and risk of limb defects in Washington State, 1980–1993. *Scand J Work Environ Health* 2000;**26**:193–8.
7. **Lin S,** Marshall EG, Davidson GK. Potential parental exposure to pesticides and limb reduction defects. *Scand J Work Environ Health* 1994;**20**:166–79.
8. **Brender J,** Suarez L, Hendricks K, *et al*. Parental occupation and neural tube defect-affected pregnancies among Mexican Americans. *J Occup Environ Med* 2002;**44**:650–6.
9. **Matte TD,** Mulinare J, Erickson JD. Case-control study of congenital-defects and parental employment in health-care. *Am J Ind Med* 1993;**24**:11–23.

10. **Nurminen T.** Maternal pesticide exposure and pregnancy outcome. *J Occup Environ Med* 1995;**37**:935–40.
11. **Shaw GM,** Gold EB. Methodological considerations in the study of parental occupational exposures and congenital malformations in offspring. *Scand J Work Environ Health* 1988;**14**:344–55.
12. **Taskinen HK.** Effects of parental occupational exposures on spontaneous abortion and congenital malformation. *Scand J Work Environ Health* 1990;**16**:297–314.
13. **Shi L,** Chia SE. A review of studies on maternal occupational exposures and birth defects, and the limitations associated with these studies. *Occup Med (Lond)* 2001;**51**:230–44.
14. **Olshan AF,** Teschke K, Baird PA. Paternal occupation and congenital-anomalies in offspring. *Am J Ind Med* 1991;**20**:447–75.
15. **Olshan AF,** De Roos AJ, Teschke K, *et al*. Neuroblastoma and parental occupation. *Cancer Causes Control* 1999;**10**:539–49.
16. **Schnitzer PG,** Teschke K, Olshan AF. A classification scheme for aggregating US census occupation and industry codes. *Am J Ind Med* 1995;**28**:185–91.
17. **McDonald AD,** McDonald JC, Armstrong B, *et al*. Congenital defects and work in pregnancy. *Br J Ind Med* 1988;**45**:581–8.
18. **Yoon PW,** Rasmussen SA, Lynberg MC, *et al*. The National Birth Defects Prevention Study. *Public Health Rep* 2001;**116**:32–40.
19. **Rasmussen SA,** Olney RS, Holmes LB, *et al*. Guidelines for case classification for the National Birth Defects Prevention Study. *Birth Defects Res A Clin Mol Teratol* 2003;**67**:193–201.
20. **Greenland S.** Bayesian perspectives for epidemiological research: I. Foundations and basic methods. *Int J Epidemiol* 2006;**35**:765–75.
21. **Greenland S.** Bayesian perspectives for epidemiological research. II. Regression analysis. *Int J Epidemiol* 2007;**36**:195–202.
22. **National Institutes of Health**. *The practical guide to the identification, evaluation and treatment of overweight and obesity in adults*. Bethesda, MD: National Institutes of Health, 2000.
23. **Blatter BM,** Roeleveld N, Zielhuis GA, *et al*. Maternal occupational exposure during pregnancy and the risk of spina bifida. *Occup Environ Med* 1996;**53**:80–6.