

ORIGINAL ARTICLE Asthma and Rhinitis

Associations between postpartum depressive symptoms and childhood asthma diminish with child age

A.L. Kozyrskyj^{1,2,3}, N.L. Letourneau⁴, L. J. Kang¹ and M. Salmani⁵¹Department of Pediatrics, University of Alberta, Edmonton, AB, Canada, ²School of Public Health, University of Alberta, Edmonton, AB, Canada,³Department of Obstetrics and Gynecology, University of Alberta, Edmonton, AB, Canada, ⁴Faculty of Nursing & Cumming School of Medicine (Pediatrics & Psychiatry), University of Calgary, Calgary, AB, Canada and ⁵Department of Mathematics & Statistics, University of New Brunswick, Fredericton, NB, CanadaClinical
&
Experimental
Allergy

Summary

Background Affecting 19% of women, postpartum depression is a major concern to the immediate health of mothers and infants. In the long-term, it has been linked to the development of early-onset asthma at school entry, but only if the depression persists beyond the postnatal period. No studies have tested whether associations with postpartum depressive symptoms and early-onset asthma phenotypes persist into later school age.

Objective To determine associations between maternal postpartum depressive symptoms and childhood asthma between the ages of 5–10 by using a nested longitudinal design.

Methods Data were drawn from the 1994–2004 administrations of the Canadian National Longitudinal Survey of Children and Youth, which tracks the health of a nationally representative sample of children in Canada. Child asthma was diagnosed by a health professional, and maternal depressive symptoms were assessed by the Centre for Epidemiological Studies Depression scale. Analyses were conducted by using a multilevel modelling approach, in which longitudinal assessments of asthma in 1696 children were nested within the exposure of postpartum depression.

Results Postpartum depressive symptoms had a 1.5-fold significant association with childhood asthma between the ages 6–8. This was independent of male sex, maternal asthma, non-immigrant status, low household socioeconomic status, being firstborn, low birthweight, low family functioning and urban–rural residence, of which the first 4 covariates elevated the risk of asthma. Statistical significance was lost at age 8 when maternal prenatal smoking replaced urban–rural residence as a covariate. At ages 9–10, an association was no longer evident.

Conclusions and Clinical Relevance Women affected by postpartum depressive symptoms are concerned about long-term health effects of their illness on their infants. Although postpartum depressive symptoms were associated with school-age asthma at ages 6 and 7, this association diminished later. Both home and school life stress should be considered in future studies on asthma development later in childhood.

Keywords asthma, epidemiology, pediatrics

Submitted 5 May 2016; revised 16 August 2016; accepted 15 September 2016

Correspondence:

Anita Kozyrskyj, Department of Pediatrics, Faculty of Medicine & Dentistry, University of Alberta, 3-527, Edmonton Clinic Health Academy (ECHA) 11405–87 Avenue, Edmonton, AB, Canada T6G 1C9.

E-mail: kozyrskyj@ualberta.ca

Cite this as: A.L. Kozyrskyj, N.L.

Letourneau, L.J. Kang and M. Salmani.

Clinical & Experimental Allergy, 2017 (47) 324–330.

Introduction

Affecting approximately 19% of women [1], and a greater percentage of new immigrant women [2], postpartum depression is of major concern to women, their infants and healthcare practitioners. Disturbingly, the majority of these women do not seek help from a healthcare practitioner for their symptoms of sadness

and despair, compulsive thoughts and feelings of inadequacy towards their infant [3]. Their infants are more likely to experience colic [4] and sleep-related problems [5] in the short-term and longer-term, developmental delays in language and cognitive functioning, and poor mental health and overweight in adolescence [6–8]. Depressive symptoms are the most common in the 3rd month after birth, decline slightly in prevalence during

the 4th month to 7th month postpartum; thereafter, the rate drops to half of the peak prevalence [1]. Up to 10% of women with perinatal depression will have problems with recurrent depression [9].

Even as late as the 1960s [10], asthma has been viewed as a psychosomatic disease, but the idea that psychosocial stress could cause asthma to develop has been tested only in recent decades [11]. The first reports found caregiver stress and parenting difficulties during the postnatal time period to elevate risk for wheeze and asthma in young children with a genetic predisposition for asthma [12–14]. New evidence from large, general population cohorts has extended these initial associations in several ways. First, maternal distress or anxiety during pregnancy was observed to be associated with preschool wheeze [15] but also with school-age asthma [16]. Second, postpartum depression was found to mediate the association between prenatal distress and preschool wheeze in girls, but it also had a direct association with wheeze [17]. Lastly, only maternal distress that persisted beyond the postnatal period has shown to increase the risk of asthma at 7 years of age [18], and Giallo et al. [19] found this association to be independent of prenatal distress.

Recognizing that most preschool wheeze is transient, in order to assess potential longlasting effects of early life stress, researchers have tested associations at the age of school entry when asthma is likely to persist. However, studies of older children include early (infancy) and late-onset asthma (age 4–5 years) phenotypes, of which late-onset asthma is less influenced by perinatal exposures [20]. Combining these two phenotypes may underestimate associations between postnatal depression and asthma in schoolchildren. As Caudri et al. [20] have done, testing age-specific asthma phenotypes in children is the best method to investigate the impact of perinatal exposures on persistent asthma. An alternative method is to implement a longitudinal, repeated measures design, which also has the benefit of assessing change in association with increasing child age. Using a multilevel modelling approach, in which longitudinal assessments of asthma in children are nested within the exposure of postpartum depression, we sought to determine age-specific associations between childhood asthma and maternal postpartum depressive symptoms (PPDS).

Methods

Ethical approval was obtained from the University of New Brunswick Research Ethics Board (approval number: 2010-127). Data were drawn from the Canadian National Longitudinal Survey of Children and Youth (NLSCY). The NLSCY, launched in 1994 by Statistics Canada, tracks the development, health and well-being

of a nationally representative sample of children in Canada over time [21]. The original cohort of children was re-interviewed every two years. For this study, six cycles of NLSCY data were used: Cycle 1 (1994–1995), Cycle 2 (1996–1997), Cycle 3 (1998–1999), Cycle 4 (2000–2001), Cycle 5 (2002–2003) and Cycle 6 (2004–2005). Children between the ages 0 through 18 months in Cycle 1 of the NLSCY were identified and followed in subsequent cycles. All information about the child was provided via computer-assisted telephone or face-to-face interviews by the person most knowledgeable about the child (PMK). Written informed consent was obtained from the PMK. The interview length varied by cycle and was approximately 1 ½ to 2 h. Among selected children in Cycle 1, only those, whose PMK was biological mother, were chosen for this study. When there was more than one child in a family, the oldest child in the family was selected, and in the case of multiple births, one child was selected at random. In total, 1696 children presented in six cycles were included in the sample for analysis.

Study measures

Child asthma. The outcome variable for this study was age-specific child asthma. The child was labelled asthmatic if he/she had been diagnosed by a health professional and had at least one of the following: (a) an attack in the past 12 months, (b) wheezing or whistling in the chest at any time in the past 12 months or (c) taking asthma medications on a regular basis. Asthma status was determined at the following ages in each cycle of survey administration: Cycle 3 (age 4–5.5), Cycle 4 (age 6–7.5), Cycle 5 (age 8–9.5) and Cycle 6 (age 10–11.5).

Maternal PPDS. Maternal PPDS was the main predictor variable, as assessed by the National Institute of Mental Health's Centre for Epidemiological Studies Depression (CESD) scale [22] or maternal report of postpartum depression (DID YOU/HER/HIS MOTHER SUFFER FROM: postpartum depression?) on the NLSCY questionnaire. The CES-D is a widely used self-report scale to measure levels of depressive symptoms during the perinatal period in the general population and also has excellent psychometric properties in both clinical and epidemiological studies with diverse populations [23, 24]. The full CES-D (20-items; scores range from 0 to 60 and a score of 16 represents a classification of depression) was rescaled by Dr. M. Boyle of the Chedoke-McMaster Hospital of McMaster University to produce a shortened version of the measure (12-items, with scores ranging from 0 to 36) with a cut-off proportional to that of the full CES-D. As such, the cut-off for depression on the 12-item NLSCY Depression Scale was set at 12. The

Cronbach's alpha of the 12-item scale was 0.82, slightly lower than the reliability of the full 20-item scale (0.85) [25]. The mother was considered to have depressive symptoms if her responses totaled a score ≥ 12 .

Covariates. Child sex, low birthweight (birthweight < 2500 g), first child (primiparous) status, urban/rural residence, maternal asthma status (asthma diagnosed by a health professional), smoking during pregnancy, single parent status (child living with one biological parent), family socioeconomic status (SES), new immigrant status (parents or child ever immigrated to Canada) and family functioning were determined from NLSCY question responses by the PMK. The derived SES variable took into account family income, and the education and occupational status of the mother and her partner. Composite scores were standardized, such that the average score among Canadian families was 0, with a standard deviation of 1. Low SES was represented by scores below -1 and high SES was represented by scores above $+1$. This scoring system has been used extensively by Statistics Canada with established reliability and validity [26, 27].

Since stress in both parents is also associated with childhood wheeze and paternal mood affects maternal distress [28], we employed the NLSCY questions on family functioning that were developed at McMaster University. They provide a global assessment of family functioning and the quality of the relationship between parents or partners. The scale included 12 questions, each of which contains four response categories, ranging in value from 0 to 3. The total score varied between 0 and 36, a high score indicating family dysfunction. Examples of questions included 'Planning family activities is difficult because we misunderstand each other' or 'In times of crisis we can turn to each other for support' with response value categories. The non-response rate for these questions was 1.9%, suggesting that the scale was acceptable to participants. The Cronbach's alpha coefficient for the total scale was 0.88 and for the 12 variables approximately 0.87 [29]. The cut-off value for low family functioning variable was 12.

Only true confounders were adjusted for in analyses. Covariates in the pathway between PPDS and child asthma, such as maternal postnatal smoking or infant breastfeeding, were not included.

Analysis

The distribution of PPDS and child asthma according to covariates was conducted to determine a candidate set of confounding factors. Hierarchical linear modelling (HLM) was performed as follows, centring on 6 years of age. The HLM Level 1 growth model for child asthma was specified by:

$$\eta_{it} = \log(\varphi_{it}/(1 - \varphi_{it}))$$

$$\eta_{it} = \beta_{0i} + \beta_{1i}(X_{it} - 6) + \beta_{2i}(X_{it} - 6)^2$$

where φ_{it} is the probability of child asthma, η_{it} is the log of odds of child asthma, X_{it} represents age in years for the i^{th} child at the time t of the measurement, β_{0i} is the log odds of asthma for the i^{th} child at age 6, that is odds of having asthma for the i^{th} child is $e^{\beta_{0i}}$, β_{1i} is the slope of the underlying trajectory (log odds trajectory) of the i^{th} child at age 6, and β_{2i} captures the curvature or acceleration in each growth trajectory.

Between-child differences are specified in the Level 2 model, where the effects of variables on β_{0i} , β_{1i} and β_{2i} are calculated using:

$$\beta_{0i} = \gamma_{00i} + \gamma_{01i}\text{PPD} + \gamma_{02i}Z_{2i} + \dots + r_{0i}$$

$$\beta_{1i} = \gamma_{10i} + \gamma_{11i}\text{PPD} + \gamma_{12i}Z_{2i} + \dots + r_{1i}$$

$$\beta_{2i} = \gamma_{20i} + \gamma_{21i}\text{PPD} + \gamma_{22i}Z_{2i} + \dots + r_{2i}$$

where γ_{00} , γ_{01} , etc., are coefficients denoting the effects of selected predictor variables, PPDS and covariates included in the model. HLM modelling was performed in the following steps: an unadjusted model, a model adjusted for baseline characteristics and a final adjusted model.

Results

In this NLSCY-based cohort of 1696 children born in 1994/1995, 20.5% of their mothers had PPDS. In total, 19% of these women smoked during pregnancy and 6% percent reported a history of asthma; in 44% of women, the study child was their firstborn. In terms of sociodemographic characteristics, 8% of women were single parents, 5% were low SES, 17% lived in rural areas, and 14% were new immigrants. The mean family functioning score for these families was 7.70 out of a total 36 for maximum family dysfunction. One quarter of families were defined as low functioning.

Half of their offspring were female and 6% had been born low birthweight. Prevalent asthma (weighted estimates from the NLSCY survey) was reported by the primary caregiver per child age group as follows: 13.4% at age 5, 14.2% at age 6, 14.6% at ages 7 and 8, 14.1% at age 9 and 13.3% at age 10.

Postpartum depressive symptoms were crudely associated with several covariates (Table 1). They were more common in women who were primiparous (21.8%), who were low SES (25%), who were single parents (35.3%) and who smoked during pregnancy (28%). PPDS tended to be present more often in new immigrant women (25.8%) and women with a history of asthma (25.4%).

A greater proportion of infants born to mothers with PPDS had low birthweights (31.8%). Child asthma at age 6 was significantly more common in male children (14.8%) and those not low birthweight (12.2%), and in the offspring of mothers who had asthma (25.4%) and were not new immigrants (13.1%). It also tended to be higher following a pregnancy with environmental tobacco smoke exposure (13.6%).

According to the unadjusted HLM model, PPDS were not associated with prevalent asthma overall (Table S1). However, the coefficient for acceleration β_2 (-0.021) was statistically significant, indicating PPDS had an impact on the rate of change of the slope or on the shape of the asthma prevalence trajectory across child age. The peak age for asthma prevalence in children of mothers with PPDS was 8.6 years, while that of children not exposed to PPDS was 8.75 (Figure S1). An examination of the slopes for the trajectories indicated that asthma prevalence peaked sooner and declined

faster among children of PPDS mothers than non-PPDS mothers.

Unadjusted odds ratio equivalents of β_2 coefficients in the HLM model at each age show that PPDS were associated with child asthma at ages 7 and 8, but not at younger or older ages (Table 2). The odds ratio for PPDS and child asthma approached non-significance with increasing age beyond age 8.

Based on the distribution of covariates in Table 1 and the literature, a decision was made to adjust a base model of PPDS and asthma with the following covariates: child sex, maternal asthma status, urban/rural residence and new immigrant status. The adjusted HLM model shows that children of asthmatic mothers were at greater risk of developing asthma overall (Table S2). Maternal asthma also impacted the rate of change in asthma prevalence, such that the odds of child asthma was highest at age 5.7 (with a slight decline afterwards, Figure S2) with a maternal history of asthma relative to no history, but the association remained for all ages. Also, girls were at lesser overall risk for asthma than boys and this did not change by age. Finally, children of new immigrant mothers were also less likely to have asthma at any age than those of non-immigrant mothers.

Independent of these covariates, the association between PPDS and child asthma remained at ages 7 and 8, and became statistically evident at age 6 (Table 2). Additional adjustment of this HLM model for firstborn status, low birthweight, household socioeconomic status or the family functioning variable did not alter associations between PPDS and asthma at ages 6, 7 or 8 (Table 3). High SES lowered the risk for asthma at lower ages (data not shown). Family dysfunction altered the shape of asthma trajectory but only minimally. In a final model that included all of these covariates and maternal smoking during pregnancy in place of urban–rural residence, the association between PPDS was retained only at ages 6 and 7. As with previous models, there was no association between PPDS and asthma at ages 9 and 10.

Table 1. Distribution of postpartum depressive symptoms (PPDS) and child asthma at age 6 by covariates

Covariate	N	PPDS		Child asthma at age 6	
		%	P-value*	%	P-value*
Sex					
Male	831	20.0		14.8	<0.01
Female	865	19.0		7.6	
Low birthweight					
No (2500 g or higher)	1608	18.8	<0.01	12.2	<0.01
Yes (<2500 g)	88	31.8		11.3	
First child status					
No	898	17.4	0.02	10.2	
Yes	798	21.8		12.2	
Urban/Rural residence					
Urban	1217	20.0		11.5	
Rural	479	18.0		10.2	
Maternal asthma status					
No	1578	19.0	0.09	10.1	<0.01
Yes	118	25.4		25.4	
Smoking during pregnancy					
No	1343	17.2	<0.01	10.5	0.09
Yes	353	28.0		13.6	
Socioeconomic status index					
Below average	901	25.0	<0.01	11.1	
Above average	795	13.2		11.2	
Single parent status					
No	1540	17.9	<0.01	11.2	
Yes	156	35.3		10.9	
Low family functioning					
No	1361	19.0		10.9	
Yes	335	21.5		11.3	
New immigrant status					
No	1568	19.0	0.06	13.1	<0.01
Yes	128	25.8		5.5	

*P-values > 0.1 not reported.

Table 2. Odds ratio for postpartum depressive symptoms (PPDS) and child asthma by age

PPDS (yes/no)	Odds Ratio (OR), 95% Confidence Interval (CI)	
	Unadjusted OR	Adjusted OR*
Age 5	1.37 (0.96, 1.96)	1.43 (0.98, 2.08)
6	1.43 (1.00, 2.04)	1.49 (1.02, 2.17)
7	1.43 (1.02, 2.00)	1.49 (1.05, 2.13)
8	1.37 (1.01, 1.86)	1.43 (1.04, 1.97)
9	1.26 (0.95, 1.67)	1.31 (0.97, 1.75)
10	1.11 (0.83, 1.50)	1.15 (0.85, 1.56)

*Adjusted for child sex, maternal asthma, urban/rural residence and new immigrant status.

Discussion

In this longitudinal follow-up of 1696 infants born to a representative sample of Canadian women, PPDS had a 1.5-fold association with childhood asthma between the ages of 6 and 8 years, independent of well-known pre- and postnatal risk factors for asthma. By 9 years of age, the association was no longer present. Asthma at school age can develop during the first year of life when mothers manifest PPDS, or after this period [20]. Since the published literature commonly groups these asthma phenotypes, one cannot deduce whether a null association with PPDS is due to a 'waning' effect of early life stress or to the inclusion of an asthma phenotype that develops after the window of PPDS exposure. HLM modelling in our study directly tested for a possible waning phenomenon, as associations with asthma prevalence were determined at different ages within the same children. Our findings add to the growing body of literature on the association between maternal distress and asthma in young children, but we were unable to show that PPDS was a significant determinant for asthma in children beyond the age of 8.

Stress pathways to asthma in younger children may originate during infancy following impaired interactions with their mothers. Postnatal depression in the mother affects her ability to be sensitive to her infant's cues; less secure mother–infant attachment is observed more often in children who develop asthma [30, 31]. In particular, less optimal maternal–infant interactions have been shown to elevate levels of infant cortisol [32]. With advancing age, an altered cortisol stress response has been observed in children with asthma [33]. Aside from inducing HPA axis changes, stress during infancy may affect normal development of the infant gut microbiome [34].

Table 3. Adjusted odds ratio for postpartum depressive symptoms (PPDS) and child asthma by age

PPDS (yes/no)	Odds Ratio (OR), 95% Confidence Interval (CI)		
	OR [†]	OR [‡]	OR [§]
Age 5	1.46 (0.99, 2.14)	1.44 (0.99, 2.07)	1.43 (0.97, 2.11)
6	1.50 (1.03, 2.21)*	1.50 (1.04, 2.15)*	1.48 (1.01, 2.95)*
7	1.48 (1.03, 2.13)*	1.49 (1.05, 2.10)*	1.47 (1.02, 2.11)*
8	1.40 (1.01, 1.94)*	1.42 (1.03, 1.95)*	1.39 (0.99, 1.93)
9	1.25 (0.93, 1.69)	1.29 (0.96, 1.74)	1.25 (0.93, 1.69)
10	1.08 (0.79, 1.46)	1.13 (0.83, 1.55)	1.08 (0.79, 1.47)

[†]Adjusted for sex, first child, low birthweight, urban/rural, maternal asthma, immigrant status and SES.

[‡]Adjusted for sex, first child, low birthweight, urban/rural, maternal asthma, immigrant status and family functioning.

[§]Adjusted for sex, first child, low birthweight, prenatal smoking, maternal asthma, immigrant status, SES and family functioning.

*Statistically significant at $P < 0.05$ level.

The diminishment in impact of early life stress on later health has also been reported for child mental health in adolescence [7]. As children grow older, they encounter stressors in social environments outside of their homes, primarily in the school environment. Teyhan et al. [35] reported that 8-year old children in the ALSPAC cohort with persistent wheeze were more likely to feel left out of school activities; children with allergic rash were more likely to be bullied. We and others have found that repeated stressful events or biomarkers of chronic stress in children predict asthma onset and persistence in adolescence [36, 37]. Likely, school life stressors are an important source of psychosocial stress in later childhood. Continued home life stress may also continue to play a role, as indicated by studies which report associations between persistent maternal depression and child asthma [18, 19]. In this study, we included a measure of family function, but it was limited to the postnatal period and was not found to be associated with childhood asthma independent of PPDS.

Our results are compatible with the lessening effect of other postnatal exposures, such as maternal smoking, on asthma in older children [38]. Environmental exposures beyond infancy, for example exposure of toddlers to house dust mite, may additionally impact lung and immune function to increase risk for asthma [39]. As also reported by Caudri et al. [20], the likelihood of childhood asthma in our study was highest for maternal history of asthma, although the association was stronger for younger children. Of interest, women with asthma had a greater tendency for PPDS. In the fully adjusted model, the PPDS association with childhood asthma was found to be independent of maternal asthma and other covariates, including immigration status. New immigrant Canadian women were marginally more likely to experience PPDS, yet much less likely to have a child with asthma. However, we were unable to stratify women by number of years since immigration, which has been reported to be a risk factor for asthma development [40].

The strength of our study was the HLM technique to test age-specific associations between postpartum depressive symptoms and childhood asthma in a representative population-based, multi-ethnic cohort that adjusted for the major determinants of asthma. PPDS was defined on the basis of maternal self-report or scores from the validated CES-D scale [22]; our prevalence rates for PPDS were comparable to other populations [1]. We were limited in our inability to define the period of asthma onset since the first questionnaire was administered 2 years after birth. Another limitation was lack of information on the chronicity of depression before or after maternal report. Although pre-existing depression is a well-known risk factor for postpartum depression [9], Gavin et al. [1] reported that up to 15%

of women will have a new episode of depression during the first 3 months postpartum, not dissimilar to the prevalence rate in this study. Further, the main exposure of interest in our study was the presence of depressive symptoms in the mother during critical periods of infant development, rather than delineating whether depressive symptoms were *de novo* or pre-existing. Indeed, the literature on risk for asthma is in relation to caregiver stress and more general measures of maternal distress in the postnatal time period. On the other hand, we did not delineate women with depressive symptoms which may have persisted; at most, this would have accounted for 10% of women with PPDS.

Women with PPDS are concerned about long-lasting health effects on their infants. While PPDS was associated with school-age asthma between 6 and 8 years of age, this association diminished as children grew older. These findings have application to clinicians and others providing support to new mothers postnatally. Clinicians may be able to reassure mothers, worried over the impact of their PPDS, that some potential outcomes

diminish with child age. While not often studied, Youash et al. [41] reported that providing mothers with information to address medical concerns about their newborns reduced their depression symptom scores in the postpartum period. Future studies on risk factors for asthma development later in childhood should also include home and school life stressors to define their role as an additional source of stress for the child.

Acknowledgements

Support for this project was provided by funding from Canada Research Chairs, and we thank Statistics Canada and the Research Data Centre at the University of New Brunswick for helping us to access data from the National Longitudinal Survey of Children and Youth.

Conflict of interest

The authors declare no conflict of interest.

References

- Gavin NI, Gaynes BN, Lohr KN, Meltzer-Brody S, Gartlehner G, Swinson T. Perinatal depression: a systematic review of prevalence and incidence. *Obstet Gynecol* 2005; **106**(5 Pt 1): 1071–83.
- Falah-Hassani K, Shiri R, Vigod S, Dennis CL. Prevalence of postpartum depression among immigrant women: a systematic review and meta-analysis. *J Psychiatr Res* 2015; **70**:67–82.
- McGarry J, Kim H, Sheng X, Egger M, Baksh L. Postpartum depression and help-seeking behavior. *J Midwifery Womens Health* 2009; **54**:50–6.
- Vik T, Grote V, Escibano J *et al.* Infantile colic, prolonged crying and maternal postnatal depression. *Acta Paediatr* 2009; **98**:1344–8.
- Field T. Postpartum depression effects on early interactions, parenting, and safety practices: a review. *Infant Behav Dev* 2010; **33**:1–6.
- Grace SL, Evindar A, Stewart DE. The effect of postpartum depression on child cognitive development and behavior: a review and critical analysis of the literature. *Arch Womens Ment Health* 2003; **6**:263–74.
- Sanger C, Iles JE, Andrew CS, Ramchandani PG. Associations between postnatal maternal depression and psychological outcomes in adolescent offspring: a systematic review. *Arch Womens Ment Health* 2015; **18**:147–62.
- Kozyrskyj AL, Zeng Y, Colman I *et al.* Maternal distress in early life predicts the waist-to-hip ratio in schoolchildren. *J Dev Orig Health Dis* 2011; **2**:72–80.
- Luoma I, Korhonen M, Salmelin RK, Helminen M, Tamminen T. Long-term trajectories of maternal depressive symptoms and their antenatal predictors. *J Affect Disord* 2015; **170**:30–8.
- Kozyrskyj AL. The social construction of childhood asthma: changing explanations of the relationship between socioeconomic status and asthma. *Crit Public Health* 1999; **9**:197–210.
- Wright RJ. Perinatal stress and early life programming of lung structure and function. *Biol Psychol* 2010; **84**:46–56.
- Wright RJ, Cohen S, Carey V, Weiss ST, Gold DR. Parental stress as a predictor of wheezing in infancy: a prospective birth-cohort study. *Am J Respir Crit Care Med* 2002; **165**:358–65.
- Klinnert MD, Nelson HS, Price MR, Adinoff AD, Leung DY, Mrazek DA. Onset and persistence of childhood asthma: predictors from infancy. *Pediatrics* 2001; **108**:E69.
- Mrazek DA, Klinnert M, Mrazek PJ *et al.* Prediction of early-onset asthma in genetically at-risk children. *Pediatr Pulmonol* 1999; **27**:85–94.
- Guxens M, Sonnenschein-van der Voort AM, Tiemeier H *et al.* Parental psychological distress during pregnancy and wheezing in preschool children: the Generation R Study. *J Allergy Clin Immunol* 2014; **133**:59–67.e1–12.
- Cookson H, Granell R, Joinson C, Ben-Shlomo Y, Henderson AJ. Mothers' anxiety during pregnancy is associated with asthma in their children. *J Allergy Clin Immunol* 2009; **123**:847–53.e11.
- Alton ME, Zeng Y, Tough SC, Mandhane PJ, Kozyrskyj AL. Postpartum depression, a direct and mediating risk factor for preschool wheeze in girls. *Pediatr Pulmonol* 2015; **51**:349–57.
- Kozyrskyj AL, Mai XM, McGrath P, Hayglass KT, Becker AB, Macneil B. Continued exposure to maternal distress in early life is associated with an increased risk of childhood asthma. *Am J Respir Crit Care Med* 2008; **177**:142–7.
- Giallo R, Bahreinian S, Brown S, Cooklin A, Kingston D, Kozyrskyj A. Maternal depressive symptoms across early childhood and asthma in school children: findings from a Longitudinal Australian Population Based Study. *PLoS ONE* 2015; **10**:e0121459.
- Caudri D, Savenije OE, Smit HA *et al.* Perinatal risk factors for wheezing

- phenotypes in the first 8 years of life. *Clin Exp Allergy* 2013; 43:1395–405.
- 21 Statistics Canada. NLSCY (National Longitudinal Survey of Children and Youth). Available at: <http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=4450>. (Last accessed 11 August 2016).
 - 22 Radloff LS. The CES-D Scale: a Self-Report Depression Scale for research in the general population. *Appl Psychol Meas* 1977; 1:385–401.
 - 23 Gaynes BN, Gavin N, Meltzer-Brody S et al. Perinatal depression: prevalence, screening accuracy, and screening outcomes. *Evid Rep Technol Assess (Summ)* 2005; 119:1–8.
 - 24 Van Lieshout RJ, Cleverley K, Jenkins JM, Georgiades K. Assessing the measurement invariance of the Center for Epidemiologic Studies Depression Scale across immigrant and non-immigrant women in the postpartum period. *Arch Womens Ment Health* 2011; 14:413–23.
 - 25 Poulin C, Hand D, Boudreau B. Validity of a 12-item version of the CES-D used in the National Longitudinal Study of Children and Youth. *Chronic Dis Can* 2005; 26:65–72.
 - 26 Statistics Canada. *National Longitudinal Survey of Children and Youth*. Ottawa, ON: Government of Canada, 1994–2001.
 - 27 Willms JD. Socioeconomic gradients for childhood vulnerability. In: Willms JD, ed. *Vulnerable children: findings from Canada's National Longitudinal Study of Children and Youth*. Edmonton, AB: University of Alberta Press, 2002:71–102.
 - 28 Bielawska-Batorowicz EKK. Depressive mood in men after the birth of their offspring in relation to a partner's depression, social support, fathers' personality and prenatal expectations. *J Reprod Infant Psychol* 2006; 24:21–9.
 - 29 Epstien NB, Ryan CE, Bishop DS, Miller IW, Keitner GI. The McMaster Model view of healthy family functioning. In: Walsh F, ed. *Normal family processes*. New York/London: The Guilford Press, 1993:138–60.
 - 30 Trapolini T, Ungerer JA, McMahon CA. Maternal depression: relations with maternal caregiving representations and emotional availability during the preschool years. *Attach Hum Dev* 2008; 10:73–90.
 - 31 Yatsenko O, Pizano J, Nikolaidis A. Revisiting maternal–infant bonding's effects on asthma: a brief history. *Cogent Psychol* 2016; 3:1161267.
 - 32 Letourneau N, Watson B, Duffett-Leger L, Hegadoren K, Tryphonopoulos P. Cortisol patterns of depressed mothers and their infants are related to maternal–infant interactive behaviours. *J Reprod Infant Psychol* 2011; 29:439–59.
 - 33 Dreger LC, Kozyrskyj AL, HayGlass KT, Becker AB, MacNeil BJ. Lower cortisol levels in children with asthma exposed to recurrent maternal distress from birth. *J Allergy Clin Immunol* 2010; 125:116–22.
 - 34 Azad MB, Kozyrskyj AL. Perinatal programming of asthma: the role of gut microbiota. *Clin Dev Immunol* 2012; 2012:932072.
 - 35 Teyhan A, Galobardes B, Henderson J. Child allergic symptoms and well-being at school: findings from ALSPAC, a UK cohort study. *PLoS ONE* 2015; 12:e0135271.
 - 36 Chen E, Hanson MD, Paterson LQ, Griffin MJ, Walker HA, Miller GE. Socioeconomic status and inflammatory processes in childhood asthma: the role of psychological stress. *J Allergy Clin Immunol* 2006; 117:1014–20.
 - 37 Bahreinian S, Ball GD, Vander Leek TK et al. Allostatic load biomarkers and asthma in adolescents. *Am J Respir Crit Care Med* 2013; 187:144–52.
 - 38 Thacher JD, Gruzieva O, Pershagen G et al. Pre- and postnatal exposure to parental smoking and allergic disease through adolescence. *Pediatrics* 2014; 134:428–34.
 - 39 Llanora GV, Ming LJ, Wei LM, van Bever HP. House dust mite sensitization in toddlers predict persistent wheeze in children between eight to fourteen years old. *Asia Pac Allergy* 2012; 2:181–6.
 - 40 Braback L, Vogt H, Hjern A. Migration and asthma medication in international adoptees and immigrant families in Sweden. *Clin Exp Allergy* 2011; 41:1108–15.
 - 41 Youash S, Campbell MK, Avison W, Penava D, Sharma V, Xie B. Influence of health information levels on postpartum depression. *Arch Womens Ment Health* 2013; 16:489–98.

Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. HLM output results for the unadjusted model in Table 2.

Table S2. HLM output results for a model adjusted for child sex, maternal asthma, urban/rural residence and new immigrant status in Table 2.

Figure S1. Average trajectory for asthma prevalence by child age conditional on PPDS (weighted model).

Figure S2. Average trajectory for conditional odds ratios for maternal asthma and child asthma by child age.

Supporting Information:

Table S1. HLM output results for the unadjusted model in Table 2

Fixed Effect	Model 1
<i>Intercept β_0</i>	
Intercept, γ_{00}	-1.883 (0.064)
PPD, γ_{01}	0.354 (0.182)
<i>Slope, β_1</i>	
Intercept, γ_{10}	0.066 (0.007)
PPD, γ_{11}	0.020 (0.023)
<i>Acceleration, β_2</i>	
Intercept, γ_{20}	-0.012 (0.002)
PPD, γ_{21}	-0.021 (0.008)

Table S2. HLM output results for a model adjusted for child sex, maternal asthma, urban/rural residence and new immigrant status in Table 2

Fixed Effect	Model 2
<i>Intercept β_0</i>	
Intercept, γ_{00}	-1.649 (0.102)
Female, γ_{01}	-0.575 (0.129)
Rural, γ_{02}	-0.018 (0.131)
Maternal Asthma, γ_{03}	1.075 (0.236)
Immigrant, γ_{04}	-0.827 (0.224)
Depression, γ_{05}	0.400 (0.192)
<i>Slope β_1</i>	
Intercept, γ_{10}	0.067 (0.012)
Female, γ_{11}	-0.001 (0.015)
Rural, γ_{12}	0.008 (0.015)
Maternal Asthma, γ_{13}	-0.009 (0.024)
Immigrant, γ_{14}	0.036 (0.019)
Depression, γ_{15}	0.022 (0.024)
<i>Acceleration β_2</i>	
Intercept, γ_{20}	-0.015 (0.003)
Female, γ_{21}	0.007 (0.005)
Rural, γ_{22}	-0.001 (0.004)
Maternal Asthma, γ_{23}	-0.014 (0.006)
Immigrant, γ_{24}	0.009 (0.008)
Depression, γ_{25}	-0.022 (0.008)

The HLM model indicates that maternal asthma had a larger impact on the growth trajectories of asthma than other covariates in the model and this varied by child age (see Figure S2). Children of new immigrant families were less likely to have asthma than children of non-immigrants at all ages. Also, girls were at less risk of asthma than boys, and there was no evidence that slopes of growth trajectories differed by sex. Associations between PPD and child asthma are discussed in the main text.

Figure S1. Average trajectory for asthma prevalence by child age conditional on PPD (weighted model)

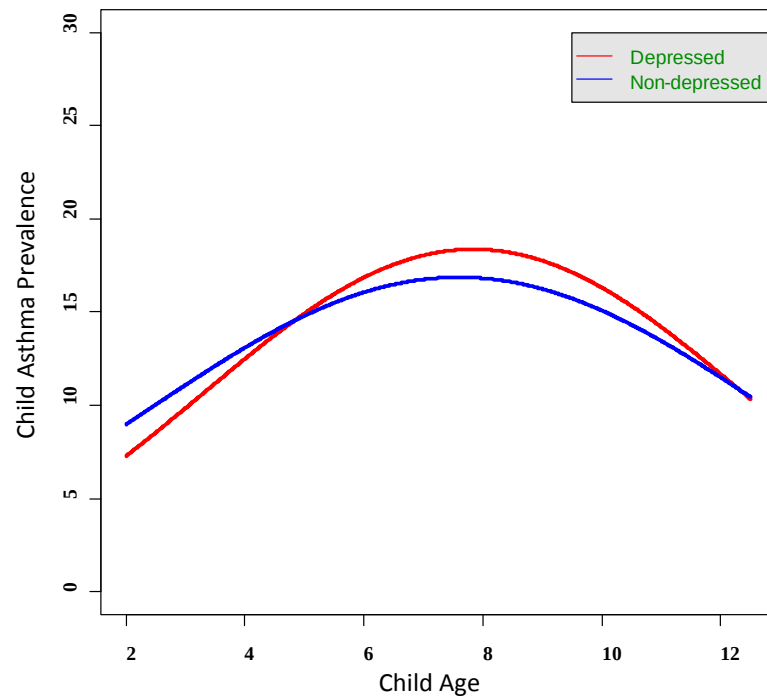


Figure S2. Average trajectory for conditional odds ratios for maternal asthma and child asthma by child age

