



Associations of household renovation materials and periods with childhood asthma, in China: A retrospective cohort study

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ARTICLE INFO

Handling Editor: Heather Stapleton

Keywords:

Asthma

Decoration materials

Household renovation

Indoor environment

Renovation periods

ABSTRACT

Background: Childhood asthma is prevalent in China. However, there is a lack of evidence on whether household renovation, including the materials used and the periods, are associated with the disease.

Objectives: To investigate the associations between household decoration materials and renovation periods, and childhood asthma and its related symptoms.

Methods: During 2010–2012, a retrospective cohort study was initiated in seven cities of China, and 40,010 children, aged 3–6 years, were recruited. Data on demographics, health status, and home decoration conditions were collected using a parent-administered questionnaire. Two-level (city-child) logistic regression analyses with adjusted odds ratios (AORs) and 95% confidence intervals (CIs) were performed to show the target associations. Sensitivity analysis was performed by stratifying data for children in the southern and northern cities.

Results: Children whose homes underwent renovation or the addition of new furniture within 1 year before pregnancy, during pregnancy, at age 0–1 year, and after age 1 year had significantly ($p < 0.05$) higher prevalence of childhood asthma and its related symptoms. The use of solid wood floors and wallpaper had significant associations (cement: AOR, 95% CI: 1.59, 1.17–2.17; lime: AOR, 95% CI: 1.31, 1.00–1.71) with an increased risk of lifetime asthma. Household renovation and the addition of new furniture during pregnancy had significant associations with lifetime asthma (renovation: AOR, 95% CI: 1.23, 1.01–1.51); lifetime wheeze (renovation: AOR, 95% CI: 1.21, 1.05–1.39; furniture: AOR, 95% CI: 1.24, 1.14–1.36), current wheeze (renovation: AOR, 95% CI: 1.21, 1.05–1.40; furniture: AOR, 95% CI: 1.23, 1.12–1.34), and current dry cough (renovation: AOR, 95% CI: 1.41, 1.23–1.63; furniture: AOR, 95% CI: 1.28, 1.17–1.41). Similar associations were found between the addition of new furniture during early childhood and lifetime asthma and its related symptoms. Except for the association between lifetime wheeze and flooring materials, the studied associations were generally stronger among children from the northern cities.

Conclusions: We confirmed that using cellulose based materials in home decoration and renovation, and adding new furniture during early childhood and pregnancy could be risk factors for childhood asthma. The association between household decoration during early childhood and childhood asthma may be stronger in the northern cities of China.

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<https://doi.org/10.1016/j.envint.2018.02.001>

Received 22 September 2017; Received in revised form 24 January 2018; Accepted 1 February 2018

0160-4120/ © 2018 Published by Elsevier Ltd.

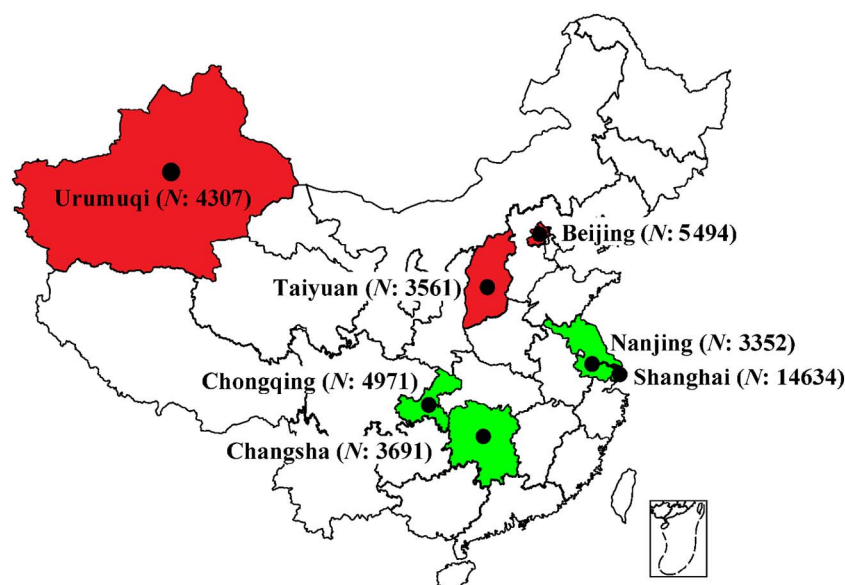


Fig. 1. Location distributions of the seven cities that participated in the China, Children, Home, Health (CCHH) survey and the sample proportions (N) in the different cities (Red: Northern cities; Green: Southern cities). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1. Introduction

As in many western countries (Asher et al., 2006; Gupta et al., 2007; Hansen et al., 2013; Pearce et al., 2007; Schernhammer et al., 2008), the prevalence of childhood asthma has rapidly increased in China (Zhang et al., 2013a). Several studies, in the last two decades, have reported that this increase in prevalence could be significantly associated with household environmental exposures (Butland et al., 1997; Ponsonby et al., 2000; Zhao et al., 2013). However, the findings of these studies were inconsistent (Bousquet et al., 2008; Gauderman et al., 2005; McConnell et al., 2002).

In China, with the rapid development of the building industry, an increasing number of new types of building materials are being applied in household decoration (Zhang et al., 2013b). The use of these materials could reduce the air change rate as well as increase the proportion of indoor volatile organic compounds (VOCs) and other pollutants, leading to worse indoor air quality and, consequently, health-related impairments (Wieslander et al., 1997; Huang et al., 2017). A few studies have found that the use of home decorations during early childhood is associated with childhood allergies and airway diseases (Deng et al., 2015, 2016; Li et al., 2014; Lin et al., 2016; Wen et al., 2015; Zhao et al., 2013). A study among 3–6-year-old children from Taiyuan, China, reported that the addition of new large furniture during pregnancy was significantly associated with an increased odds of childhood wheeze, allergic rhinitis and eczema, while renovating the home at age 0–1 year was associated with an increased risk for rhinitis and eczema symptoms (Zhao et al., 2013). A similar study from Changsha, China, found that the addition of new large furniture at age 0–1 year, was a risk factor for the increased odds of childhood eczema and allergic rhinitis, and exposure to household renovation during pregnancy was a risk factor for childhood asthma and eczema (Deng et al., 2016).

In the present retrospective cohort study, we investigated the associations between household renovation periods and decoration materials (wall and floor) with childhood doctor-diagnosed lifetime asthma and parent-reported asthmatic symptoms among 3–6-year-old children, in China. We hypothesized that exposure to household renovation during pregnancy and early childhood, as well as the use of new types of decoration materials (in the place of lime and cement) could be significantly associated with an increase in the risk of childhood asthma and its related symptoms (wheeze and dry cough).

2. Materials and methods

2.1. Study design and participants

The retrospective cohort study, was based on the first phase of the China, Children, Homes, Health (CCHH) study—a large multi-centre study conducted on kindergarten children in China, with the aim of investigating the associations between indoor environment and asthma, eczema, rhinitis and other allergies (Zhang et al., 2013a). Through the use of the same standard and validated parent-administered questionnaire used in that study, we collected data on demographics, residential characteristics, household environment, as well as lifetime-ever and current (within the past 1 year before this survey) health status of the children. Questions on childhood allergic diseases/symptoms were based on the International Study on Asthma and Allergies in Childhood (ISAAC) (Asher et al., 1995). Questions on residential characteristics and household environment were based on the Dampness in Building and Health study (Bornehag et al., 2004) in Sweden, modified for Chinese habits. The CCHH study was approved by the Ethical Committee of the School of Public Health, Fudan University, China. Informed written consent was obtained from all the participants' parents and guardians before the survey.

From October 2010 to April 2012, a total of 59,337 questionnaires for parents of children, from > 200 kindergartens, across seven cities (Shanghai, Chongqing, Nanjing, Changsha, Taiyuan, Urumqi, and Beijing), were randomly distributed (Zhang et al., 2013a) (Fig. 1). We finally collected 42,666 responses (response rate: 71.9%) pertaining to 1–8-year-old children. In the present study, questionnaires from 1784 children younger than 3 years old or older than 6 years old were excluded, as were 872 investigated children in whom information on age was absent. The questionnaires of 40,010 children, aged 3–6 years, were finally included.

2.2. Health outcomes

Lifetime asthma and its related symptoms, including lifetime wheeze, current wheeze and current dry cough, were investigated in the present study. Hereinafter, “lifetime asthma” is defined by the question “Has your child ever been diagnosed with asthma by a doctor? (Yes or No)”; “lifetime wheeze” by “Has your child ever had wheeze or whistling in the chest at any time in the past (Yes or No)”; “current wheeze” by “Has your

Table 1
Children's demographic characteristics and prevalence of the diseases, under different covariate conditions.

Items	All the children					Children whose residence did not change since birth					
	Sample sizes, <i>n</i> (%)	Current wheeze		Current dry cough		Sample sizes, <i>n</i> (%)	Lifetime asthma		Lifetime wheeze		
		Prevalence, <i>n</i> (%)	<i>p</i>	Prevalence, <i>n</i> (%)	<i>p</i>		Prevalence, <i>n</i> (%)	<i>p</i>	Prevalence, <i>n</i> (%)	<i>p</i>	
Total	40,010 (100.0)	7847 (20.1)		6757 (17.2)		24,503 (100.0)	1823 (7.6)		4963 (20.7)		
Sex											
Boys	20,684 (51.8)	4384 (21.7)		3479 (17.2)		12,540 (51.3)	1124 (9.1)		2429 (23.2)		
Girls	19,176 (48.2)	3441 (18.4)		< 0.001	3254 (17.3)	0.772	11,881 (48.7)	695 (6.0)		< 0.001	2097 (18.0)
Age (years)											
3	7091 (17.7)	1567 (22.6)		1387 (20.0)		4620 (18.9)	249 (5.5)		863 (19.0)		
4	14,041 (35.1)	2872 (20.9)		2526 (18.3)		8747 (35.7)	629 (7.3)		1812 (21.1)		
5	12,352 (30.9)	2324 (19.2)		1938 (16.0)		7320 (29.8)	599 (8.3)		1520 (21.2)		
6	6526 (16.3)	1145 (17.5)		< 0.001	906 (14.2)	< 0.001	3816 (15.6)	346 (9.3)		< 0.001	768 (20.6)
Family atopic history											
Yes	7725 (19.7)	2351 (30.9)		1996 (26.2)		4755 (19.7)	801 (17.1)		1632 (34.9)		
No	30,866 (80.3)	5245 (17.3)		< 0.001	4606 (15.1)	< 0.001	19,126 (80.3)	985 (5.2)		< 0.001	3209 (17.1)
Environmental tobacco smoke exposure											
Yes	22,295 (58.9)	4646 (21.3)		3914(17.8)		13,958 (59.6)	1058 (7.7)		2918 (21.3)		
No	15,581 (41.1)	2850 (18.6)		< 0.001	2602 (16.9)	0.012	9449 (40.4)	695 (6.0)		0.462	1853 (20.0)
Residence ownership											
Owner	24,868 (64.2)	4816 (19.8)		4346 (17.7)		16,457 (68.5)	1252 (7.7)		3332 (20.7)		
Renter	13,855 (35.8)	2800 (20.6)		0.029	2234 (16.3)	< 0.001	7567 (31.5)	530 (7.1)		0.052	1539 (20.7)
Residence location											
Urban	29,432 (75.9)	5707 (19.8)		5044 (17.4)		18,901 (78.3)	1458 (7.8)		3798 (20.5)		
Suburban	7822 (20.2)	1609 (20.9)		1332 (17.2)		4448 (18.4)	309 (7.1)		957 (21.9)		
Rural	1527 (3.9)	344 (23.1)		0.001	216 (14.4)	0.013	808 (3.3)	38 (4.9)		0.003	148 (18.9)
Household dampness											
Yes	25,218 (73.7)	1239 (14.0)		1143 (12.8)		15,693 (73.3)	1297 (8.4)		3636 (23.6)		
No	8993 (26.3)	5639 (22.8)		< 0.001	4772 (19.2)	< 0.001	5717 (26.7)	322 (5.7)		< 0.001	803 (14.3)

Figures in bold indicate p -values < 0.05. The sums of some of the items were not equal to the total sample sizes (40010) due to missing data in these items.

child had wheeze or whistling in the chest in the last 12 months (Yes or No)”; and “current dry cough” by “Has your child had a dry cough at night for more than two weeks (coughs caused by a cold or chest infection were excluded) (Yes or No)”. Children were recognized as having these outcomes when their answers to these questions were “Yes”. For lifetime asthma and wheeze, to eliminate the impact of changing residences on the estimated associations with household renovation, only those children ($N = 24,503$, 64.8%) who lived in the same residence since birth were selected for the study, based on the question “Has your child lived at the present address since birth (Yes vs. No)”.

2.3. Household renovation

In the present study, we focused on household exposure factors such as the decoration materials used in the children's bedrooms as well as the renovation periods. The specific questions for household decoration were as follows: Which flooring materials were used in the child's bedroom? (solid wood; laminate floor; cement; tiles/ceramic, stone); Which wall materials were used in the child's bedroom? (wallpaper; oil paint; lime; emulsion paint; cement); Was new large furniture added during the following periods: 1 year before pregnancy, during pregnancy, when the child was 0–1 year old, or when the child was older than 1 year? (Yes vs. No); Was your home renovated during the following periods: 1 year before pregnancy, during pregnancy, when the child was 0–1 year old, or when the child was older than 1 year? (Yes vs. No). We considered children as having had these exposures when the answers were ‘Yes’. We excluded children whose families used two or more kinds of floor and wall covering materials from the present analysis.

2.4. Covariates and statistical analysis

According to the existing literature (Litonjua et al., 1999; de Marco

et al., 2000; Gilliland et al., 2001; Bornehag et al., 2004, 2005; Postma, 2007; Jaakkola et al., 2013; Sun and Sundell, 2013), we took into consideration age (3 vs. 4 vs. 5 vs. 6-year-olds), sex (boys vs. girls), ownership of the residence (owner vs. renter), family atopic history (yes vs. no), environmental tobacco smoke (ETS) exposure (yes vs. no), indoor dampness (yes vs. no), and residential location (urban vs. suburban vs. rural). Among these covariates, ownership of the residence and residential location were considered proxies of a family's socioeconomic status (SES). Family atopic history was defined as parents or other family members having asthma or other allergic diseases/symptoms. ETS exposure was defined as the presence of smokers in the family. We defined indoor dampness as reports of at least one of the following dampness-related indicators in the present residence: visible mould spots, visible damp stains, water damage, damp clothing/beddings, condensation on windows during winter, and mouldy odour.

All data statistical analyses were performed by STATA 11.0 (STATA Corp., Texas, USA). All analyses were restricted to children with complete data on the variables required in a particular analysis. Due to missing data on various items, the sums of the number of children with different symptoms or different exposures in the subgroups were not equal to the total numbers. Pearson's chi-squared test was applied to compare the prevalence of asthma and its related symptoms among children in the different subgroups, stratified by the covariates as well as renovation/the addition of new furniture during different renovation periods. Two-level (city and child) logistic regression analyses were performed to evaluate the adjusted associations of household decoration materials and renovation periods with asthma and its related symptoms. Due to the notable differences in the annual ambient climate (temperature and relative humidity) as well as the household ventilation and heating habits among residents living in the northern and southern cities of China (Zhang et al., 2013a), with the aim of exploring the differences in the target associations between these two districts, we

conducted a sensitivity analysis by stratifying data for the northern cities (Beijing, Taiyuan, and Urumqi) which were located north of the Yangtze River and southern cities (Shanghai, Nanjing, Changsha, and Chongqing) of China (Fig. 1). Children, in whose homes cement flooring and lime wall material were used, and those whose homes were not renovated or did not have new furniture were considered the reference groups in all the regression analyses. Adjusted odd ratios (AORs) with their 95% confidence intervals (CIs) were used to quantify the target associations. Statistical significance was set at a p -value < 0.05 in all the analyses.

3. Results

Table 1 shows the demographic information and household environment of the participants. A total of 51.8% of the participants were boys and 19.7% had a family atopic history. A total of 58.9% children were exposed to ETS and 64.2% lived in the residences owned by their parents. Household dampness indicators were reported in 73.7% of the families and most of these families (75.9%) lived in urban areas.

Table 1 also presents data on the prevalence of asthma and its related symptoms among children, stratified by the covariates. The prevalence of lifetime asthma and wheeze were 7.6% and 20.7%, respectively, among children whose residences did not change since birth. The prevalence of current wheeze and dry cough were 20.1% and 17.2%, respectively. Asthma and wheeze (lifetime and current) were more prevalent among the boys than girls. Significant differences ($p < 0.001$) in the prevalence of asthma and its related symptoms were observed among children of different ages. We also found a significantly ($p < 0.001$) higher prevalence of asthma and its symptoms among children with a family atopic history than those without. Notably higher prevalence of current wheeze and dry cough were observed among children exposed to ETS. Children whose families owned the home of residence presented significantly higher prevalence of current dry cough than those who did not. Children who lived in urban areas had the highest prevalence of lifetime asthma and current dry cough, whereas those in rural areas had the highest prevalence of current wheeze. Children with household dampness-related exposures had significantly higher prevalence of asthma and its related symptoms than those without.

In terms of household decoration materials and periods (Table 2), the largest proportion of families used solid wood (43.1%) as floor covering, and emulsion paint (53.5%) as wall covering. A total of 16.0% and 17.6% of these children had homes which underwent renovation within 1 year before pregnancy and after age 1 year, respectively. A total of 28.9% and 36.3% of their families added new furniture 1 year before pregnancy and after age 1 year, respectively. Similar sample distributions, stratified by the studied factors, were observed on comparing children whose homes of residence did not change since birth and all the surveyed children (Table 2).

In the present study, children whose homes underwent renovation and the addition of new furniture, in different periods, reported higher prevalence of asthma and its related symptoms, and most of these associations were significant (Table 3).

In the two-level hierarchic logistic regression analyses, with respect to household decoration materials (Fig. 2 and supplemental Table S1), compared to cement, using solid wood as floor covering was significantly associated with an increasing odds of lifetime asthma (AOR, 95% CI: 1.59 1.17–2.17), lifetime wheeze (1.20, 1.10–1.44) and current dry cough (1.27, 1.10–1.47). Compared to lime, the use of wallpaper in wall covering had a positive association with lifetime asthma (1.31, 1.00–1.71). With regards to household renovation periods (Fig. 3 and supplemental Table S2), we observed positive associations between household renovation and adding new furniture 1 year before pregnancy, during pregnancy, at age 0–1 year, and after age 1 year, and lifetime asthma and its related symptoms. Moreover, most of the associations were statistically significant. Household renovation during

Table 2

Sample distributions of the children, with different decoration materials and periods.

Items	Sample sizes, n (%)	
	All the children (N = 40,010)	Children whose residence did not change since birth (N = 24,503)
Floor covering materials		
Solid wood	16,281 (43.1)	10,465 (44.6)
Laminate flooring	8894 (23.6)	5642 (24.0)
Tiles/ceramic, stone	8159 (21.6)	5029 (21.4)
Cement	3097 (8.2)	1562 (6.7)
Wall covering materials		
Emulsion paint	20,118 (53.5)	13,048 (55.8)
Oil paint	3653 (9.7)	2292 (9.8)
Wallpaper	3758 (10.0)	2087 (8.9)
Cement	2172 (5.8)	1339 (5.7)
Lime	4502 (12.0)	2472 (10.6)
Periods of household renovation (yes)		
Within 1 year before pregnancy	5546 (16.0)	3869 (18.4)
During pregnancy	1437 (4.2)	918 (4.5)
At age 0–1 year	1097 (3.2)	537 (2.6)
After age 1 year	6041 (17.6)	2336 (11.3)
Periods of adding new furniture (yes)		
Within 1 year before pregnancy	9742 (28.9)	6524 (26.6)
During pregnancy	4232 (13.3)	2708 (13.5)
At age 0–1 year	4363 (13.9)	2592 (13.1)
After age 1 year	12,464 (36.3)	6527 (30.9)

pregnancy increased, by 23%, the odds of lifetime asthma (1.23, 1.01–1.51), by 21%, that of lifetime wheeze (1.21, 1.05–1.39), and by 21%, that of current wheeze (1.21, 1.05–1.40). Household renovation during age 0–1 year increased, by 26%, the odds of current wheeze (1.26, 1.08–1.48), and by 33% that of current dry cough (1.33, 1.13–1.56). Adding new furniture during pregnancy increased, by 24%, the odds of lifetime wheeze (1.24, 1.14–1.36), by 23% the odds of current wheeze (1.23, 1.12–1.34), and by 28% the odds of current dry cough (1.28, 1.17–1.41). Positive associations were also found between the addition of new furniture during other periods, and lifetime asthma and its related symptoms.

In the sensitivity analyses, for the household decoration materials (Fig. 4 and supplemental Table S3), the target associations among the children prominently differed between the northern and southern cities. Except for the associations of lifetime wheeze with floor covering materials, most of the associations were generally stronger among children from the northern cities than those from the southern cities. With regards to household renovation periods and asthma and its symptoms (Fig. 5 and supplemental Table S3), compared to the entire sample, similar positive associations were observed among children from the northern and southern cities. Furthermore, the association of household renovation or the addition of new furniture during different early childhood periods with asthma and its related symptoms was stronger in the northern cities than the southern cities.

4. Discussion

In this retrospective cohort study, we found that children whose homes underwent renovation and the addition of new furniture during early childhood (within 1 year before pregnancy, during pregnancy, at age 0–1 year, and after age 1 year) had significantly higher prevalence of lifetime asthma and its related symptoms. In the two-level logistic regression analyses, compared to cement, the use of solid wood as a floor covering material was a risk factor for lifetime asthma and lifetime wheeze. Compared to lime, the use of wallpaper as wall covering may increase the risk of lifetime asthma. Except for the association between

Table 3
Prevalence of asthma and its related symptoms in children, under different renovation situations.

Items	Lifetime asthma, (%)	<i>p</i>	Lifetime wheeze, (%)	<i>p</i>	Current wheeze, (%)	<i>p</i>	Current cough, (%)	<i>p</i>
Household renovation (yes vs. no)								
Within 1 year before pregnancy	8.4 vs. 7.8	0.113	23.2 vs. 21.0	0.001	22.5 vs. 20.2	< 0.001	19.0 vs. 17.9	0.026
During pregnancy	9.7 vs. 8.0	0.038	25.7 vs. 21.4	0.001	24.2 vs. 20.5	0.001	23.1 vs. 17.9	< 0.001
At age 0–1 year	11.1 vs. 8.0	0.005	21.2 vs. 21.6	0.440	24.5 vs. 20.6	0.001	22.4 vs. 18.0	< 0.001
After age 1 year	8.0 vs. 8.1	0.507	20.1 vs. 21.7	0.043	21.7 vs. 20.4	0.016	20.1 vs. 17.6	< 0.001
Addition of new furniture (yes vs. no)								
Within 1 year before pregnancy	8.4 vs. 6.9	< 0.001	23.1 vs. 19.2	< 0.001	22.4 vs. 18.6	< 0.001	19.2 vs. 15.9	< 0.001
During pregnancy	7.6 vs. 7.1	0.157	23.2 vs. 19.3	< 0.001	22.7 vs. 18.8	< 0.001	20.7 vs. 16.2	< 0.001
At age 0–1 year	8.0 vs. 7.1	0.050	22.1 vs. 19.5	0.001	23.3 vs. 18.7	< 0.001	20.3 vs. 16.2	< 0.001
After age 1 year	7.8 vs. 7.0	0.026	21.0 vs. 19.4	0.004	21.3 vs. 18.6	< 0.001	19.0 vs. 16.0	< 0.001

Figures in bold indicate *p*-values < 0.05.

lifetime wheeze and floor materials, all the associations were generally stronger for children from the northern cities than for those from the southern cities.

The findings of several previous studies (Dong et al., 2014; Jaakkola et al., 1999, 2004, 2006; Sun and Sundell, 2013; Wieslander et al., 1997) are in agreement with ours, in that the use of wallpaper and solid wood for household decoration could be associated with the risk of asthma and its related symptoms, although the associated decoration materials varied in these studies. A cross-sectional study of children aged 2–14 years in seven cities of northeast China reported that the use of new hardwood floors and new wall coverings in the residence, in the two years preceding the survey, was significantly associated with both lifetime-ever doctor-diagnosed asthma and current cough (Dong et al., 2014). A case-control study from Norway indicated that the use of PVC flooring (compared to wood or parquet flooring) (AOR, 95% CI: 1.89, 1.14–3.14) and textile wallpaper as a wall covering material (compared to lime-painted walls and ceilings) (1.58, 0.98–2.54) was associated with an increased risk of childhood bronchial obstruction (Jaakkola et al., 1999). A cross-sectional study of 8–12-year-old schoolchildren in Russia found that household renovations using new linoleum flooring (1.36, 1.00–1.86) and new wall coverings (1.20, 0.95–1.52) during the 12 months preceding the survey was associated with wheezing among these children during the same period (Jaakkola et al., 2004). A pollution-based case-control study of 21–63-year-old adults living in Finland reported that the use of plastic wall materials (2.43, 1.03–5.75) and plastic flooring in the residence, in the 12 months preceding the study (1.81, 1.06–3.08), was significantly associated with a higher odds of the onset of asthma (Jaakkola et al., 2006). A cross-sectional study

from northeast Texas suggested that using carpet as floor covering was associated with rhinitis (1.58, 1.00–2.50), while using laminated panels as wall covering was associated with wheezing (4.72, 1.75–12.68) (Sun and Sundell, 2013). Generally, plastic and cellulose based materials (carpet, wallpaper, solid wood, and laminated panel) are aggregated and installed or pasted using chemical/synthetic adhesives, and these could be potential emission sources of indoor pollutants such as formaldehyde, VOCs, and semi-volatile organic compounds (SVOCs) (Böhm et al., 2012). These indoor pollutants have been reported to be associated with childhood asthma and its related symptoms (Jensen et al., 2001; Mendell, 2007; Herberth et al., 2009). The present study's findings suggest that using cellulose based materials (wallpaper as wall covering, and solid wood as floor covering, compared to lime and cement, respectively) as decoration materials could be risk factors for childhood asthma and its related symptoms.

Our findings, that 1) household renovation and the addition of new furniture were associated with childhood asthma and its related symptoms; and that 2) these associations were generally stronger during pregnancy and at age 0–1 year than within 1 year before pregnancy and after age 1 year are supported by previous studies (Deng et al., 2015, 2016; Dong et al., 2014; Franck et al., 2014; Li et al., 2014; Lin et al., 2016; Reynolds and Finlay, 2017; Wang et al., 2014; Wen et al., 2015; Zhao et al., 2013). In particular, Deng and colleagues found that household renovation (AOR, 95% CI: 2.34, 1.16–4.74) and the addition of new furniture (2.21, 1.29–3.81) had significant associations with the increased odds of childhood asthma among 3–6-year-old children in Changsha, China (Deng et al., 2015). A cross-sectional study performed in seven cities of northeast China found that household

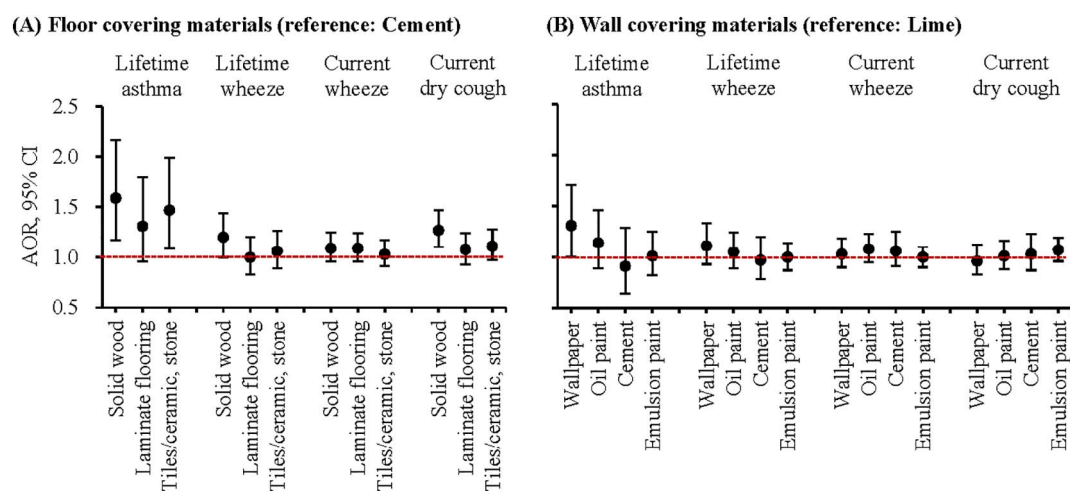


Fig. 2. Adjusted associations of household decoration materials with lifetime asthma and its related symptoms. The adjusted factors, in the two-level logistic regression model, included children's sex, age, family atopic history, residence ownership, environment tobacco smoke exposure, indoor dampness, and residence location. The detailed AORs and their 95% CIs, and the *p*-values are presented in supplemental Table S2.

AOR, adjusted odds ratio; CI, confidence interval.

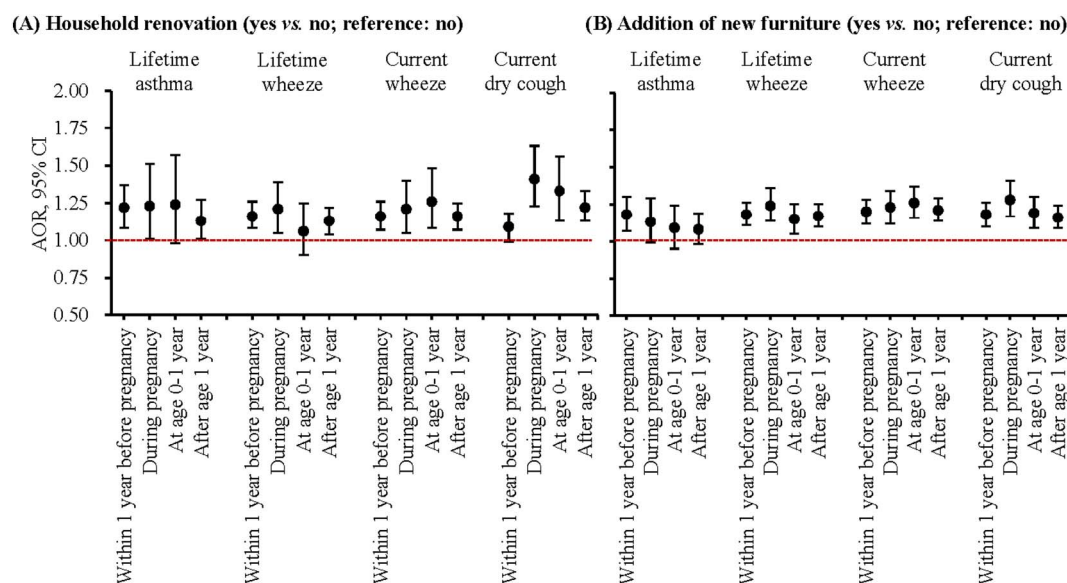
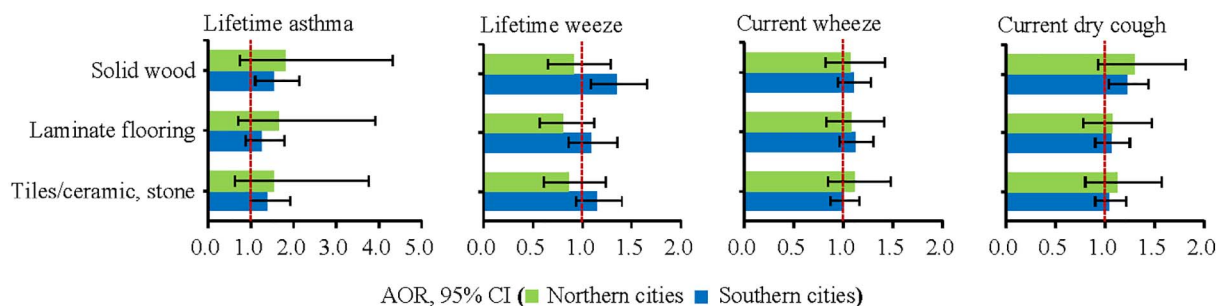


Fig. 3. Adjusted associations of the household renovation periods with lifetime asthma and its related symptoms. The adjusted factors, in the two-level logistic regression model, included the children's sex, age, family atopic history, residence ownership, environment tobacco smoke exposure, indoor dampness, and residence location. The detailed AORs and their 95% CIs, and the *p*-values are presented in supplemental Table S3. AOR, adjusted odds ratio; CI, confidence interval.

renovation in the 2 years preceding the study were significantly associated with the increased odds of lifetime asthma (1.35, 1.22–1.49), current wheeze (1.26, 1.14–1.39), and cough (1.36, 1.25–1.47) (Dong et al., 2014). A birth cohort study in Germany also suggested that household renovation with a change in flooring were associated with doctor-treated wheeze (5.20, 1.77–15.25), during the first 12 months after birth (Franck et al., 2014). These findings further confirmed that the prenatal period and early-life were critical windows for children's

health (Franck et al., 2014; Reynolds and Finlay, 2017), and that household renovation in early childhood was a risk factor for childhood asthma and its related symptoms. Building renovation materials are important sources of indoor VOCs and SVOCs (Franck et al., 2014; Mendell, 2007). Exposure to these pollutants through home renovation activities, during early life, may play an important role in foetal growth and immune system operations that are associated with the presence of childhood allergic diseases/symptoms (Holgate, 2012; Holtzman, 2012;

(A) Floor covering materials (reference: Cement)



(B) Wall covering materials (reference: Lime)

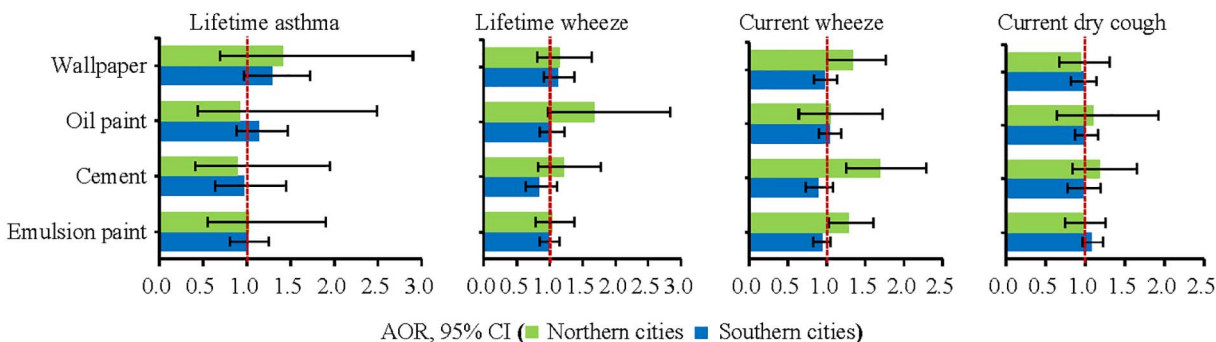


Fig. 4. Adjusted associations of household decoration materials with lifetime asthma and its related symptoms, stratified by northern and southern cities. The adjusted factors, in the two-level logistic regression model, included the children's sex, age, family atopic history, residence ownership, and environment tobacco smoke exposure, indoor dampness, and residence location. The detailed AORs and their 95% CIs, and the *p*-values are presented in supplemental Table S4. AOR, adjusted odds ratio; CI, confidence interval.

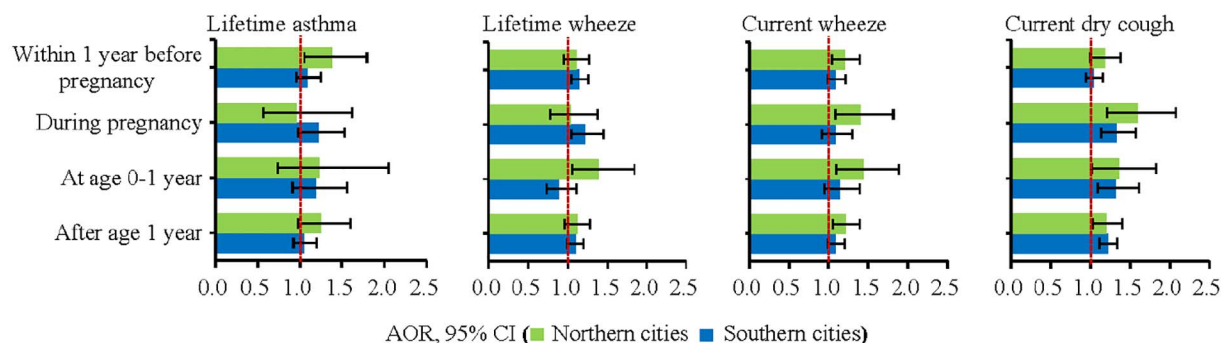
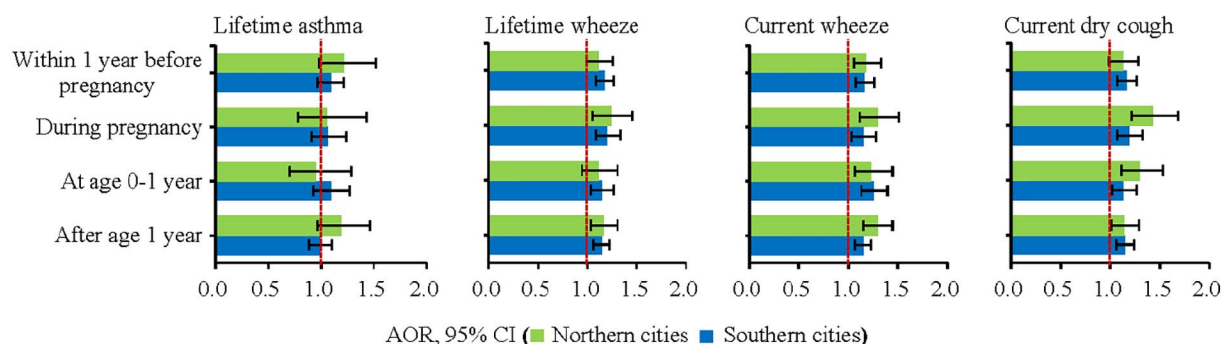
(A) Household renovation (yes vs. no; reference: no)**(B) Addition of new furniture (yes vs. no; reference: no)**

Fig. 5. Adjusted associations of household renovation periods with lifetime asthma and its related symptoms. The adjusted factors, in the two-level logistic regression model, included the children's sex, age, family atopic history, residence ownership, environment tobacco smoke exposure, indoor dampness, and residence location. The detailed AORs and their 95% CIs, and the *p*-values are presented in supplemental Table S5. AOR, adjusted odds ratio; CI, confidence interval.

Sarma et al., 2006).

Furthermore, we found that household renovation and the addition of new furniture within 1 year before pregnancy were also associated with childhood asthma and its related symptoms. Generally, after dwellings are renovated, a significant proportion of indoor air pollutants (VOCs and formaldehyde) from the renovation materials and new furniture remain during the first 6 months (Grump et al., 1997). We suspect that exposure to these household renovation pollutants, within 1 year before pregnancy, may have epigenetic effects on male sperm, thus influencing the offspring's health later in life. A case-control study of 398 male painters, who were exposed to organic solvents, and 302 male carpenters with little or no such exposure suggested that the painters' offspring had a significantly higher risk of congenital malformations than the carpenters' offspring (Hooiveld et al., 2006). More studies are warranted to verify this finding, and the possible biological mechanism behind it.

A recent study (Liu et al., 2017) suggested that household renovation during pregnancy had significant associations with low birth weight (LBW) and preterm birth (PTB), which also were found to be associated with childhood asthma and wheeze (Been et al., 2014; Leung et al., 2016). Under similar exposure situations, the foetal immune systems of PTB and LBW children could be more susceptible to pollutants from renovation products, and thus these children could have higher odds of the development of asthma and its related symptoms during childhood (Herberth et al., 2013). There is a need for more research to verify the deduction that parental exposure to pollutants from household renovation, before and during pregnancy, leads to adverse birth outcomes and defects of the foetal immune system, thereby resulting in childhood asthma and its related symptoms among their children.

We also found that the associations of household renovation materials and periods with childhood asthma and its related symptoms were generally stronger among children in the northern cities than among

those in the southern cities. These differences in associations could be related to differences in the climate, as well as the heating and ventilation habits between the northern and southern cities (Zhang et al., 2013a). Household ventilation was an important factor behind the emission of VOCs and SVOCs from building products and materials (Wolkoff, 1998; Claeson et al., 2009; Guo et al., 2013; Xiong et al., 2016; Huang et al., 2017). Generally, VOCs and SVOCs from building products and materials in newly-renovated homes can be emitted and eliminated faster with better ventilation (Guo et al., 2013; Xiong et al., 2016; Huang et al., 2017). In China, residences in the southern residences may have better natural ventilation than those in the northern cities, especially in winter, through the opening of windows, according to our analysis (Table S5). Besides, the higher building airtightness and usage of insulation materials to keep indoors warm and save heating energy in winter also could result in the worse ventilation status in the homes in the northern cities than those in the southern cities (Zhai et al., 2013). Therefore, compared to children whose homes did not undergo renovation in early childhood, the impact of household decoration-related pollutants on children in the northern cities could be stronger than that of those in the children from the southern cities. More in-depth studies are warranted to verify this hypothesis.

There are some limitations to our study. Firstly, selection and recall biases cannot be ruled out in retrospective questionnaire-based studies. In the present study, except for the fact that asthma was confirmed based on the parent's report of a doctor's diagnosis, other asthmatic symptoms and environmental exposures were determined by parents' observations and recall reports. Therefore, reporting biases and errors pertaining to the disease/its symptoms and other questionnaire-based information could exist, leading to deviations in our analyses. Secondly, we used housing ownership and city, but not the widely-used family income and parental education, as SES indicators. It may not have been possible for the residual confounding by SES to be fully adjusted in the regression analyses. Thirdly, although we considered several covariates,

there are perhaps other factors, such as maternal nutrition and medication (Beckhaus et al., 2015), dietary habits (Andrusaityte et al., 2017), ambient air pollution (Liu et al., 2016) and temperature (Cong et al., 2017), which could also confound our targeted associations. Nevertheless, the sample size of this study was large, and the response rate was high. The studied seven cities covered different development levels, climates and lifestyles. Therefore, this study could represent the situation in China.

5. Conclusions

This study provides new evidence that the use of cellulose based materials in home decoration as well as household renovation, and the addition of new furniture within 1 year before pregnancy, during pregnancy, at age 0–1 year and after age 1 year could be risk factors for childhood asthma. The influence of household renovation and the addition of new furniture during pregnancy and at age 0–1 year, on childhood health, could be stronger than at within 1 year before pregnancy and after age 1 year. The impact of early household decoration on childhood asthma may be stronger in the northern cities of China than in the southern cities.

Acknowledgements

This work was financially supported by the National Key Research and Development Program (2017YFC0702700), Shanghai Sailing Program (17YF1412800) and the Innovation Program of Shanghai Municipal Education Commission (14ZZ132). We thank the Shanghai Municipal and District Bureau of Education for their support in the questionnaire survey. We appreciate all the students, parents, children, and others who were involved in the CCHH study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envint.2018.02.001>.

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