



Prenatal and perinatal home environment and reported onset of wheeze, rhinitis and eczema symptoms in preschool children in Northern China



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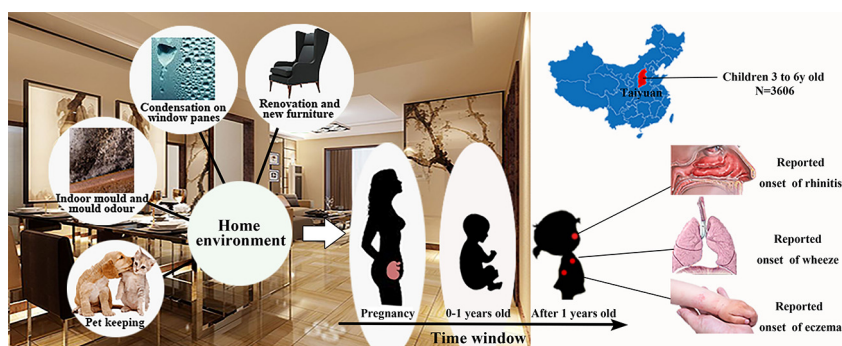
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HIGHLIGHTS

- Early life redecoration can increase reported onset of wheeze, rhinitis and eczema.
- Perinatal indoor mould can increase reported onset of wheeze, rhinitis and eczema
- Perinatal window pane condensation can increase reported onset of wheeze and rhinitis
- Dog keeping can increase reported onset of wheeze and eczema
- Perinatal indoor air quality can influence postnatal wheeze, rhinitis and eczema

GRAPHICAL ABSTRACT



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ABSTRACT

Early life environment can affect asthma and allergies but few cohort studies on this issue are available from China. Our aim was to investigate reported onset of childhood wheeze, rhinitis and eczema symptoms in relation to prenatal, perinatal and postnatal home environment. Data on home environment and symptoms (ISAAC based questions) in first two years of life and in the past 12 months were reported by parents of the children (3–6 y) in a cross-sectional questionnaire survey in ten day care centers in Taiyuan, northern China (N = 3606). Changes of symptoms from the first 2 years of life to the past 12 months (recall period) were calculated retrospectively. Multilevel logistic regression analysis was applied. Reported onset of wheeze, rhinitis and eczema were 11.8%, 22.2% and 3.3%, respectively. Redecorating during pregnancy increased reported onset of rhinitis (OR = 2.29) and eczema (OR = 4.91). New furniture during pregnancy increased reported onset of rhinitis (OR = 1.47). Perinatal indoor mould increased reported onset of wheeze (OR = 1.51), rhinitis (OR = 1.65) and eczema (OR = 1.91). Perinatal mould odour increased reported onset of wheeze (OR = 1.85). Perinatal window pane condensation increased reported onset of wheeze (OR = 1.54) and rhinitis (OR = 1.24). Perinatal stuffy air and dry air in the home increased reported onset of all three symptoms (ORs 1.46–2.24). Dog keeping increased reported onset of wheeze (OR = 1.69) and eczema (OR = 2.13). Based on principal component analysis, four exposure scores were calculated (renovation, new furniture, mould and indoor air quality scores). Dose-response relationships were observed between these exposure scores and reported onset of symptoms. In conclusion, prenatal and postnatal exposure to emissions from renovation and new furniture can increase reported onset of childhood

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wheeze, rhinitis and eczema. Perinatal indoor mould, mould odour, condensation on window panes and impaired indoor air quality at home can be associated with reported development of wheeze, rhinitis and eczema in preschoolers in northern China.

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1. Introduction

Childhood asthma has risen in many countries since the mid-20th century (Asher et al., 1995; Dietert and Zelikoff, 2008), including China (Zhao et al., 2013a, 2013b; Zhang et al., 2013). Childhood asthma is usually allergic asthma (Chen et al., 2011), often accompanied by rhinitis and eczema (Depner et al., 2014; Lin et al., 2016).

We spend more than 90% of our time indoors. Environmental tobacco smoke (ETS) (Heinrich, 2011; Ciaccio and Gentile, 2013; Gonzalez-Barcala et al., 2013) is an established indoor risk factor for childhood asthma, rhinitis and allergic diseases and ETS can increase the risk of atopic dermatitis (Kantor et al., 2016; Saulyte et al., 2014). Mould and dampness are other established indoor risk factors for childhood asthma and rhinitis (Heinrich, 2011; Tischer et al., 2011) and dermatitis (Weinmayr et al., 2013; Ukawa et al., 2013; Shpakou et al., 2012). Chemical emissions from renovation can increase childhood allergic disease (Mendell, 2007) and dermatitis (Herbarth et al., 2006; Lee et al., 2007) but few incidence studies exist on associations between early life indoor chemical exposure and childhood asthma, rhinitis and dermatitis. Indoor environmental exposure in early life can influence the risk of paediatric allergic disease including asthma (Dietert and Zelikoff, 2008). Foetal exposure during pregnancy (Hehua et al., 2017) or after birth can prime the immune system (Gehring et al., 2015). Thus, it is important in early life epidemiological studies to assess indoor exposure in prenatal as well as in postnatal periods.

The rapid development of the Chinese economy has influenced building technology and the indoor environment in Chinese homes (Sun et al., 2019). Thus, more research is needed on the impact of modern home environments in China for childhood asthma and allergies. The CCHH study (China Child Home Health) is a multi-center study including pre-school children in different cities across China (Zhang et al., 2013; Norbäck et al., 2018a, 2018b; Norbäck et al., 2019). The CCHH study includes Taiyuan, the major city (4 million inhabitants) in the Shanxi province in northern China. The Shanxi province had previously high levels of outdoor air pollution from coal burning (Zhao et al., 2013a, 2013b) but, despite this severe outdoor air pollution, the prevalence of childhood diagnosed asthma and rhinitis (Norbäck et al., 2018b) and eosinophilic airway inflammation (measured as FeNO) (Zhao et al., 2013b) remains relatively low as compared to more developed parts of China. Thus, it is relevant to study associations between early life exposure in the home and childhood asthma and allergic diseases especially in this province.

Our aim was to study reported onset of childhood wheeze, rhinitis and eczema in pre-schoolers in the city of Taiyuan in relation to selected prenatal, perinatal and postnatal home environment. We hypothesized that indoor exposure in the home environment, during pregnancy, around birth or after birth can influence the reported development of childhood wheeze, rhinitis and eczema symptoms. The study was restricted to home environment factors with specific questions on exposure during pregnancy or around birth. We used retrospective information in a cross-sectional questionnaire survey to calculate reported onset of symptoms as in previous publications (Norbäck et al., 2019; Lin et al., 2016; Lu et al., 2021).

2. Material and methods

2.1. Study population and study design

We recruited children from 10 randomly selected day care centers (kindergartens) in Taiyuan city, China (Fig. 1). Taiyuan is located

500 km south west of Beijing and is a heavily polluted city. The study recruited randomly selected daycare centers from five districts of Taiyuan including Yingze, Wanbailin, Xinhualin, Xiaodian and Jiancaopin districts. Taiyuan has six districts. The sixth district was excluded because it was very small. All children selected in the day care centers were invited. For each child, a questionnaire about the home environment and health in different periods of early life was sent out. It was collected by the day care centers and answered by parents or other guardians. A total of 4988 children were invited and 3701 participated (74.2% participation rate). This article was restricted to children 3 to 6 year old ($n = 3606$) since few children attend a day care center before being 3 year old, and they usually start school at 6 years age. The data collection was cross-sectional (a one time questionnaire survey) but questions on symptoms at different time points allowed us to make a retrospective estimate of the reported onset of wheeze, rhinitis and eczema.

2.2. Ethics

The study used data from the Taiyuan part of the Chinese Children Home Health study (CCHH) (Zhang et al., 2013). The CCHH study was approved by Fudan University in Shanghai (the Medical Research Ethics Committee of School of Public Health). The parents gave informed consent and the children approved their participation.

2.3. Health outcomes

In this study, we focused on three dependent health variables; wheeze, rhinitis and eczema. Standardized questions on these

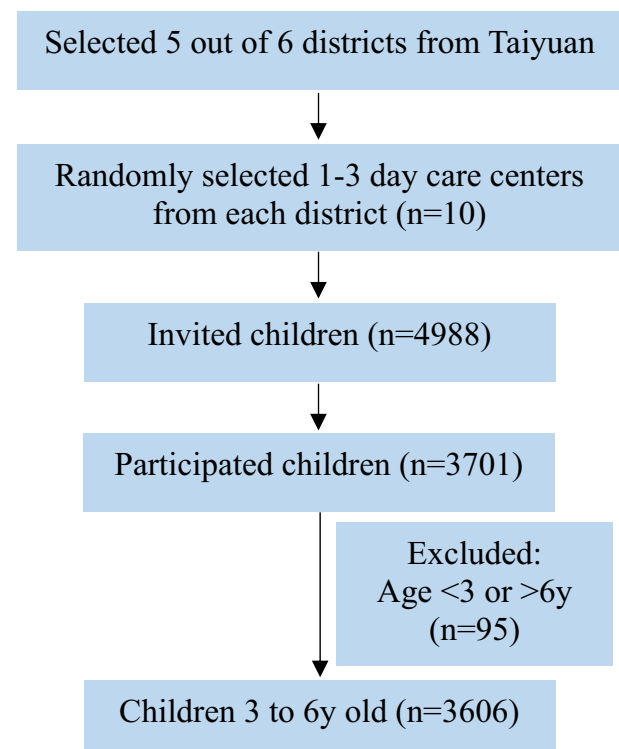


Fig. 1. Selections of participants.

symptoms were obtained from the large ISAAC study (Asher et al., 1995). Wheeze was defined as having wheezing or whistling in the chest. Rhinitis was defined as sneezing or having a runny nose or a blocked nose when not having a cold or the flu. Eczema was defined as having itch or rash (eczema) from time to time for at least 6 months. There were three yes/no questions asking for any wheeze, rhinitis or eczema in the last 12 months (ISAAC 12 months questions). Moreover, there were three yes/no questions asking if the child had ever had any wheeze, rhinitis or eczema (ISAAC ever questions). If yes on ever having symptoms, for each type of symptom we asked for a specification of the time period with four alternatives: prior to 1 year of age, 1–2 y of age, 3–4 y of age and more than 4y of age (additional questions not found in the ISAAC study).

Symptoms reported in the first 2 years of life were compared to symptoms reported in the last 12 months. Thus we retrospectively calculated reported onset for each symptom. Reported onset of wheeze was defined as not having wheeze at the first 2 years of life but having wheeze at age 3–6 years. Reported onset of rhinitis and eczema were defined the same way. We defined the interval time as age minus two.

2.4. Co-variables included in the statistical models

Nine potential confounders were included in all statistical models: children's gender, age, parents' allergic history (mother or father), season of birth, breastfeeding (yes vs. no), birth weight (<2.5 kg vs. ≥2.5 kg), home size (<60 m² vs. 60–100 m² vs. >100 m²), maternal occupation when being pregnant with the child and prenatal or postnatal environmental tobacco smoke in the home (one combined ETS variable). The question on ETS included tobacco smoke from any person living in the home (not just smoking by the father or the mother). Data on these variables were obtained from the questionnaire. We selected these variables because the literature in general, as well as previous publications from the CCHH study, have indicated they could be relevant confounders. The question on maternal occupation during pregnancy had ten pre-set options: unemployed, farmer, teacher, office work, housewife, health care work, industrial work, sales person, student and other job. Home size can be a proxy variable of socioeconomic status (Juhn et al., 2011) linked to family income (Norbäck et al., 2018a). In a study from Tianjin, China, among families with pre-school children living homes with less than 60 m² area, 41% had an annual family income less than 50,000 RMB. When the study was performed, 50,000 RMB was approximately equal to 6000 Euro. In homes with 60–100 m² area, 20% had less than 50,000 RMB. In homes with more than 100 m² area, 13% had less than 50,000 RMB. The same was true for large home size and high family income. In homes with less than 60 m² area, 24% had an annual family income more than 100,000 RMB. In homes with 60–100 m² area, 46% had more than 100,000 RMB. In homes with more than 100 m² area, 64% had more than 100,000 RMB (Norbäck et al., 2018a).

2.5. Home environment

The English version of the questionnaire is available in a methodological publication (Zhang et al., 2013). Questions on mould odour, dry air and stuffy air are commonly used in questionnaires on perceived indoor air quality (e.g. Andersson, 1998). The following home environment questions, answered by a parent or another guardian, were used in this article as independent exposure variables:

1. Have you got new furniture in the home of the child during the time periods stated below:
 - a) When the mother was pregnant with the child (yes/no)
 - b) In the first year of life (yes/no)
 - c) After the child was 1 year old (yes/no)

2. Has the home of the child been renovated during the time periods stated below:
 - a) When the mother was pregnant with the child (yes/no)
 - b) In the first year of life (yes/no)
 - c) After the child was 1 year old (yes/no)
3. Cat keeping
 - a) In the home when the child was born (yes/no)
 - b) In the current home (yes/no)
4. Dog keeping
 - a) In the home when the child was born (yes/no)
 - b) In the current home (yes/no)
5. Visible mould in the child's home around birth (yes/no)
6. Condensation on window panes in winter in the home around birth (yes/no)
7. Mould odour in the home around birth (yes/no)
8. Air dryness in the home around birth (yes/no)
9. Stuffy air in the home around birth (yes/no)

Due to low numbers, question 3a and 3b (ever cat keeping) and question 4a and 4b (ever dog keeping) were combined to two variables. Question 5–9, asking about the situation in the home around birth, was defined as perinatal exposure.

These questions were asked for a specific time window, irrespectively if the child had changed home since pregnancy/birth or not. In addition, there were some questions on other indoor factors in the current home, including type of cooking fuel, air conditioners, air humidifiers, air cleaners and a question on window opening habits. They were used in statistical models with additional adjustment for these indoor variables not included in the aim of the study.

2.6. Current home environment and outdoor air pollution

The CCHH questionnaire has a number of questions on the current home environment, including type of cooking fuels, presence of air conditioning, air humidifier, and air cleaners and window opening habits. Since there were no questions on these types of exposure during pregnancy or around birth, they were not included in the aims of the study. However, we adjusted for these home environment factors in additional statistical models, to evaluate potential confounding by the current home environment. Outdoor air pollution could be a potential confounder in our study. We had the address of the day care centers but not the home address of the child. We modelled the air pollution levels outside the day care centers, a mean for a 12 months period before the study was performed, using a previously published model (Norbäck et al., 2019). Then, we investigated correlation between air pollution outside the day care centers and the proportion of children in each day care center exposed to the household environmental factors included in our aim.

2.7. Statistical analysis

Pearson correlation coefficient was used to calculate correlations. Time between the first 2 years of life and the past 12 months (here called "interval time") was calculated as age minus two years.

Health associations for home environment factors were analyzed by multi-level logistic regression models (2-levels: day care center and child) controlling for the eight co-variables (gender, age, parental asthma or allergy, birth season, breast feeding, birth weight, home size and maternal occupation). Initially, we put one exposure in each logistic regression model with control for the nine co-variables (one exposure models). As a next step, we performed mutually adjusted models, keeping home environment factors with the same exposure time window with $p < 0.1$ in the same mutually adjusted model. Moreover, we investigated

statistical interaction between ETS exposure and other life home exposures significant in the one exposure models, considering a *p*-value for interaction <0.1 as a significant interaction. Finally, factor analysis (varimax rotation with Kaiser normalization) was used to identify factors among the exposure variables. Exposure variables belonging to the same factors were combined to exposure scores analyzed in additional multi-level logistic regression models.

Factor analysis, cross table analysis and correlation analysis were conducted by the SPSS software (version 22.0). Two-level multiple logistic regression models were analyzed by STATA 13.0 statistical package.

3. Results

When the children were born more than half of the homes (51.6%) had condensation on window panes in winter and 12.1% had visible mould in the homes. A total of 27.7%, 24.4%, and 5.7% had air dryness, stuffy odour and mould odour at home when the children were born, respectively. A total of 2.5% had redecoration during pregnancy, 2.9% in the first year of life and 17.7% had redecoration after the children were one year old. A total of 8.6% got new furniture during pregnancy, 8.7% in the first year of life and 35.7% got new furniture after the children were one year old. Cat and dog keeping were uncommon, 1.9% had cats and 7.5% had dogs (either at birth or in the current home) (Table 1). Most children lived in urban or suburban areas, only 2.2% lived in rural areas (data not shown in the table).

Descriptive data for the co-variables are given in Table 2. In total, 52.0% were boys. Most children were 4 year (35.3%) or 5 year (31.6%) old. Fewer children were 3 year (21.7%) or 6 y (11.4%) old. Most mothers had white collar jobs during pregnancy (61.4%), only 2.4% were industrial workers and only 0.8% were farmers. In total, 66.3% of the children were exposed to ETS at home (during pregnancy or after birth). Almost half (48.1%) of the fathers smoked when their wives were pregnant and 50.5% smoked after the child was born. Only 0.1% of the mothers smoked when they were pregnant and 1.0% smoked after the child was born.

A total of 10.2%, had wheeze, 20.2% rhinitis and 7.7% eczema in the first 2 years of life. A total of 13.1%, had wheeze, 30.5% rhinitis and 4.4% eczema in the last 12 months. A total of 377 children had reported

Table 1

Descriptive statistics of home environmental factors for preschoolers in Taiyuan (N = 3606).

Home environment factors	Prevalence % (n)
Perinatal window pane condensation ^a	51.6(1560)
Perinatal visible indoor mould ^a	12.1(408)
Perinatal air dryness ^a	27.7(951)
Perinatal stuffy air ^a	24.4(844)
Perinatal moldy odor ^a	5.7(195)
Redecoration	
During pregnancy	2.5(90)
0–1 years old	2.9(104)
After 1 year old ^b	17.7(640)
New furniture	
During pregnancy	8.6(310)
0–1 years old	8.7(314)
After 1 years old ^b	35.7(1286)
New furniture or redecoration	
During pregnancy	9.6(345)
0–1 years old	9.8(352)
After 1 years old ^b	38.8(1400)
Pet keeping	
Cats	1.9(68)
Dogs	7.5(271)

Children's asthma/allergic symptoms and home environment factors were self-reported data.

^a Factors were only asked 'When children were born'.

^b After 1 years old: time window from 1 years old to the date of completing the questionnaire.

Table 2

Covariates information of all participants (N = 3606).

Co-variables	Proportion or prevalence, n (%)
Gender	
Boy	1876(52.0)
Girl	1730(48.0)
Age (years)	
3	783(21.7)
4	1273(35.3)
5	1139(31.6)
6	411(11.4)
Parents' allergic history	
Yes	399(11.4)
No	3104(88.6)
Birth season	
Spring (March–May)	846(23.5)
Summer (June–August)	982(27.2)
Autumn (September–November)	916(25.4)
Winter (December–February)	862(23.9)
Breastfeeding	
Yes	3186(89.7)
No	365(10.3)
Birth weight (kg)	
<2.5	62(1.8)
≥2.5	3459(98.2)
Internal size of current home (m ²)	
<60	1051(29.7)
60–100	1531(43.3)
>100	955(27.0)
Maternal occupation during pregnancy	
Not occupationally active ^a	1270(35.4)
Farmer	30(0.8)
Industrial worker	85(2.4)
White-collar worker ^b	2202(61.4)
Environmental tobacco smoking (ETS) at home	
Yes	2391(66.3)
No	1215(33.7)

^a House wife (5.5%) or unemployed (29.9%).

^b White-collar worker was defined as office worker (28.5%), teacher (12.0%), medical staff (5.2%), salesperson (4.8%), student (0.3%) and other occupations (10.6%).

onset of wheeze (11.8%), 618 had reported onset of rhinitis (22.2%) and 105 (3.3%) had reported onset of eczema from the first 2 years to the last 1 year of life. The interval time was 2.3 years on average (Table 3).

Initially, health associations were calculated for reported onset of symptoms, including the eight co-variables (one model per exposure) (Table 4). ETS was one of the co-variables. There were no significant association between ETS exposure and reported onset of wheeze, rhinitis or eczema. Visible mould around birth increased onset of all three health variables. Window pane condensation increased reported onset of wheeze and rhinitis. Mould odour increased reported onset of wheeze, only. Air dryness increased reported onset of all health variables. Stuffy odour increased reported onset of wheeze and rhinitis. Redecoration during pregnancy increased reported onset of rhinitis and eczema. Redecoration when the child was 0–1 y old increased reported onset of eczema. Redecoration after the child was 1 y old increased reported onset of rhinitis and eczema. Getting new furniture during pregnancy increased reported onset of wheeze and rhinitis. Buying new

Table 3

The numbers (N), baseline prevalence (%) of reported onset of children's asthmatic/allergic symptoms (calculated by comparing the first 2 years and the last year of life).

	Reported prevalence in the first two years of life (%)	Reported prevalence in the last 12 months (%)	Reported onset of symptoms		
			N ^a	N ^b	%
Wheeze	10.2	13.1	377	3192	11.8
Rhinitis	20.2	30.5	618	2779	22.2
Eczema	7.7	4.4	105	3180	3.3

^a Number of children with the particular symptom in the last 12 months but reported to not have had the particular symptom in the first two years of life.

^b Number of children without the particular symptom in the first two years of life.

Table 4

Associations between home environment factors and reported onset of symptoms in preschoolers in Taiyuan (N = 3606).

		Reported onset		
		Wheeze	Rhinitis	Eczema
Perinatal home environmental factors	Visible mould ^a	1.51(1.08,2.91)**	1.65(1.24,2.20)***	1.91(1.13,3.22)*
	Window pane condensation ^a	1.54(1.21,1.96)***	1.24(1.02,1.52)*	1.37(0.89,2.09)
	Moldy odour ^a	1.85(1.21,2.82)***	1.27(0.82,1.96)	0.97(0.39,2.44)
	Air dryness ^a	1.78(1.39,2.28)***	1.47(1.19,1.82)***	2.09(1.37,3.20)***
	Stuffy odour ^a	2.24(1.75,2.87)***	1.67(1.34,2.08)***	1.52(0.97,2.40)
Redecoration	During pregnancy	1.49(0.78,2.88)	2.29(1.32,4.02)**	4.91(3.02,11.87)***
	0–1 years old	1.78(0.99,3.18)	1.55(0.90,2.66)	3.21(1.29,8.01)*
	After 1 years old ^b	1.14(0.83,1.57)	1.52(1.15,1.99)**	2.06(1.14,3.76)*
New furniture	During pregnancy	1.56(1.07,2.60)*	1.47(1.07,2.04)*	1.71(0.95,3.09)
	0–1 years old	1.72(1.21,2.48)**	1.28(0.91,1.79)	1.64(0.90,2.96)
	After 1 years old ^b	1.43(1.13,1.83)**	1.32(1.08,1.62)**	1.16(0.77,1.79)
Pet keeping	Cats	1.47(0.61,3.52)	1.04(0.47,2.29)	NA
	Dogs	1.69(1.09,2.65)*	1.43(0.81,1.06)	2.14(1.06,4.36)*

Odds ratios (OR) with 95% CI calculated in the two-level binary logistic regression adjusting for gender, age, parents' allergic history, birth season, breastfeeding, birth weight, house size, ETS at home and maternal occupation during pregnancy.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

^a Factors were only asked 'When children were born'.

^b After 1 years old: time window from 1 years old to the date of completing the questionnaire.

furniture when the child was 0–1 y old increased reported onset of wheeze. Buying new furniture after the child was 1 y old increased reported onset of wheeze and rhinitis. Dog keeping increased reported onset of wheeze and eczema (Table 4). We found no significant association between ETS exposure and reported onset of wheeze, rhinitis or dermatitis. Moreover, we found no significant interactions (p -value for interaction > 0.1) from ETS exposure on any of the early life home exposures associations significant in Table 4.

As a next step, we calculated mutually adjusted models for the different time windows, including variables within the same time window with $p < 0.1$ in the one exposure models. For reported onset of wheeze, perinatal visible mould, air dryness and stuffy odour were significant. For reported onset of rhinitis, perinatal visible mould, air dryness and stuffy odour were significant. For reported onset of eczema, perinatal visible mould and air dryness were significant. When keeping renovation and new furniture in the same models, redecoration was the strongest chemical exposure factor (results only reported in text).

The factor analysis identified five factors. The first factor consisted of redecoration during pregnancy, redecoration in the first year of life and redecoration after first year of life. The second factor consisted of getting new furniture during pregnancy, getting new furniture in the first year of life and getting new furniture after first year of life. The third factor consisted of perinatal visible mould and mould odour. The fourth factor consisted of perinatal window pane condensation in winter, stuffy air and dry air perception (all three variables were positively correlated). The fifth factor consisted of cat and dog keeping (inversely related).

Based on the factor analysis, we created four environmental scores. The redecoration score (0–2) was created from the three questions on renovation; coded 0 if no redecoration, coded 1 if redecoration once, and code 2 if redecoration more than one time. The new furniture score (0–2) was created from the three questions on new furniture; coded 0 if getting new furniture once, coded 1 if getting new furniture once, and code 2 if getting new furniture more than one time. A mould score (0–2) was created from the two questions on perinatal visible mould and mould odour; coded 0 if no on both questions, code 1 if yes on one question and coded 2 if yes on both questions. An indoor air quality score (0–2) was created from the three questions on perinatal dry air, stuffy air and window pane condensation in winter; coded 0 if no on all questions, code 1 if yes on one question and coded 2 if yes on more than one questions. Since only dog keeping was related to health, no furry pet score was created. Finally, we analyzed health associations for the four environmental scores Dose response relationships

were observed for all scores, with the highest ORs for the highest scores (Table 5).

In the current home, 13.4% used electricity for cooking, 81.1% used gas but no biomass and 5.5% used biomass for cooking. Moreover, 54.7% used air conditioning, 59.9% air humidifiers and 6.1% air cleaners. Frequent window opening habits by season were as follows: never 27.3%, one season 25.0%, two seasons 13.0%, three seasons 19.9% and all four seasons 14.8%. All significant associations between the home environment scores and reported onset of symptoms, reported in Table 5, remained significant after further adjustment for other home environment variables (type of cooking fuel, air conditioning, air humidifier, air cleaner and window opening index), with only small changes of ORs (data not shown).

When the questionnaire study was performed, the modelled mean air pollution levels outside the day care centers were 43.4 $\mu\text{g}/\text{m}^3$ of $\text{PM}_{2.5}$ (range 12.2–91.5), 81.7 $\mu\text{g}/\text{m}^3$ of PM_{10} (range 24.1–155.1), 32.6 $\mu\text{g}/\text{m}^3$ of NO_2 (range 23.5–62.1) and 59.1 $\mu\text{g}/\text{m}^3$ of SO_2 (range 25.0–119.2). We found no significant correlations between these modelled levels of air pollution and the proportion (%) of homes with parental reports on new furniture, redecoration, window pane condensation, mould odour, stuffy air or dry air in the current home.

4. Discussion

We found associations between pre-natal, perinatal and post-natal home environment and reported onset of wheeze, rhinitis and eczema in pre-schoolchildren in northern China. Different time windows in early life had different health associations. Sources of chemical emissions such as new furniture and redecoration, during pregnancy as well as after birth, were important risk factors for reported onset of symptoms. Poor perceived air quality around birth, reported by the parents, was another important risk factor linked to increased reported onset of symptoms. Moreover, perinatal exposure to indoor mould, mould odour, and condensation on window panes were risk factors for reported onset of symptoms. Finally, dog keeping was a risk factor for reported onset of wheeze and onset of eczema. Associations between prenatal exposure to outdoor air pollution and later development of asthma has been reported in a number of studies (Hehua et al., 2017). The reason is suggested to be early life programming of the immune system in critical time windows during pregnancy. Our study indicate that such early-life programming of the immune system may also occur for chemical household exposure.

Table 5

Associations between four home environment scores and reported onset of symptoms in preschoolers in Taiyuan (N = 3606).

	Score ^a	Prevalence (%)	Reported onset		
			Wheeze	Rhinitis	Eczema
Redecoration score (0–2)	0	69.5	1.00	1.00	1.00
	1	29.1	1.12(0.81–1.55)	1.49(1.12–1.97)**	1.84(0.98–3.43)
	2	1.4	1.27(0.36–4.45)	2.03(0.75–5.48)	9.19(2.41–34.97)**
New furniture score (0–2)	0	61.3	1.00	1.00	1.00
	1	31.5	1.38(1.06–1.79)*	1.26(1.01–1.58)*	1.09(0.68–1.73)
	2	7.2	1.65(1.07–2.54)*	1.58(1.09–2.30)*	1.51(0.73–3.13)
Perinatal mould score (0–2)	0	82.7	1.00	1.00	1.00
	1	15.5	1.56(1.15–2.12)**	1.73(1.33–2.26)***	1.91(1.17–3.13)**
	2	1.8	2.23(1.00–4.95)*	2.25(1.01–4.97)*	NA
Perinatal indoor air score (0–2)	0	40.0	1.00	1.00	1.00
	1	41.2	1.47(1.11–1.96)**	1.26(1.01–1.57)*	1.32(0.81–2.16)
	2	18.7	2.84(2.08–3.87)***	1.83(1.39–2.39)***	1.85(1.07–3.22)*

Odds ratios (OR) with 95% CI calculated in the two-level binary logistic regression adjusting for gender, age, parents' allergic history, birth season, breastfeeding, birth weight, house size, ETS at home and maternal occupation during pregnancy.

NA = not available (too small numbers).

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

The reported onset in the national CCHH study, calculated the same way as in our study, was 15.8% for wheeze (Norbäck et al., 2019), 38.9% for rhinitis (Norbäck et al., 2019) and 7.9% for eczema symptoms (Lu et al., 2021). The interval time in the national CCHH study was 2.4 years on average, similar as in our study (2.3 years). Thus, it can be concluded that the reported onset rate of wheeze was similar in Taiyuan as compared to national data, but reported onset of rhinitis and eczema symptoms were lower. One explanation to the lower reported onset rate could be the low level of furry pet related allergic symptoms among children in Taiyuan (Lu et al., 2020). Moreover, Taiyuan is a relatively poor area in China and children in poorer areas in China tend to have less doctor-diagnosed rhinitis (Norbäck et al., 2018b).

We found that getting new furniture during pregnancy or after birth was a risk factor for reported onset of wheeze and rhinitis. New furniture can be a source of chemical emissions, especially formaldehyde, after buying the furniture. In homes with chipboard based furniture, high levels of formaldehyde (320–950 $\mu\text{g}/\text{m}^3$) have been measured in China the year after buying the furniture (Cai et al., 2002). Redecoration of the home during pregnancy or after birth was a risk factor for wheeze, rhinitis and eczema. New paint can be a source of formaldehyde and volatile chemicals such as glycol ethers the year after indoor painting (Wieslander et al., 1997; Wieslander and Norbäck, 2010). Our results concerning early life exposure to new furniture emissions and redecoration as a risk factor for asthmatic symptoms agree with previous studies from China (Fan et al., 2017; Lin et al., 2016; Li et al., 2020; Norbäck et al., 2019; Deng et al., 2016) and Germany (Franck et al., 2014) but most of these studies did not separate exposure during different time windows in early life.

Perinatal exposure to indoor mould and mould odour was a risk factor for reported onset wheeze and rhinitis. This is in agreement with previous review articles for asthma (Quansah et al., 2012) and rhinitis (Jaakkola et al., 2013) and two previous Chinese studies (Deng et al., 2016; Lin et al., 2016). Another dampness-related risk factor was perinatal condensation on window panes in wintertime, related to reported onset of wheeze and rhinitis. Condensation on the inside of window panes in winter is an indicator of humid air and poor ventilation and is linked to house dust mite allergen levels in dust (Emenius et al., 2000; Luczynska et al., 1998). Our results concerning window pane condensation agrees with some previous studies from China (Deng et al., 2016; Norbäck et al., 2019), Japan (Takaoka and Norback, 2011) and Sweden (Wang et al., 2014).

Poor subjective air quality in the home when the child was born, reported as stuffy odour or air dryness by the parents, were two consistent

risk factors associated with reported onset of wheeze, rhinitis and eczema. This agrees with one Chinese study reporting that perinatal exposure to air dryness was a risk factor for onset of childhood wheeze (Lin et al., 2016). One important issue is to what extent subjective air quality is an indicator of objective indoor exposure. Perceived air quality in an experimental setting is the foundation of existing ventilation standards (e.g. AHRAE, 1999). In field studies, reports on mould odour (Wang et al., 2017) and stuffy air (Nordstrom et al., 1995; Engvall et al., 2005) was associated with low ventilation flow. Moreover, reports on stuffy air (Finell et al., 2021) and dry air (Nordstrom et al., 1995) were associated with observed building dampness. In a recent Chinese study, both perceived dry air and humid air were associated with dampness indices, and the authors concluded that the sensation of air dryness may not be due to the actual indoor relative humidity, but rather to indoor air irritants (Qian et al., 2016). Thus, subjective reports on air quality in the home when the child was born may reflect indoor exposure associated with development of wheeze, rhinitis and eczema later in life.

We found that dog keeping increased reported onset of wheeze and eczema. Dogs can contaminate the home environment with allergens and microbial compounds such as endotoxin (Chen et al., 2012; Tischer et al., 2015), gram-positive bacteria (Tischer et al., 2015) and mould (Tischer et al., 2015). One review article summarized the health aspects of early life furry pet keeping (Chen et al., 2010). Most birth cohort studies on early life dog exposure found no effects on wheeze or asthma. However, some studies found that exposure to dogs in infancy could protect against allergic sensitization. Available cross-sectional studies showed inconsistent results (Chen et al., 2010). Since most available health studies on dog keeping are from western countries, more studies on early life dog keeping and respiratory health are needed from other parts of the world.

The study has some strengths. We used standardized ISAAC questions on wheeze, rhinitis and eczema (Asher et al., 1995). Moreover, we asked about exposure during different parts of prenatal and postnatal periods. By comparing reports on symptoms in the first two years of life and the last 12 months, we could retrospectively calculate reported onset of symptom. Moreover, we adjusted for a number of potential confounders.

The study has some limitations. When performing a number of statistical tests, some false positive results can occur. However, many of our associations were highly significant ($p < 0.01$) which limits the risk of false positives. One limitation is that for some types of indoor factors (dampness, mould and perceived indoor air quality) we only have information on perinatal exposure. Another limitation is that we had

no indoor exposure measurements or clinical investigations. Older siblings can protect against allergy development in more affluent countries (Strachan et al., 2015). However, our study was performed when China still had the one child policy, so very few children had any siblings. This is the reason for not including siblings as co-variate in our study. We had no information on parental education level, but we included two socio-economic proxy variables as co-variables: maternal occupation during pregnancy and size of the home (an indicator of family income). Size of the home can be an indicator of socio-economic status (Juhn et al., 2011) and family income in Chinese urban population (Norbäck et al., 2018a). In rural areas, where price of houses is lower, poorer families can have larger homes. However, in our study in Taiyuan, only 2.2% of the families lived in rural areas.

Outdoor air pollution is a severe problem in China and can influence child health. We had no information on the home address of the children. We have published results on associations between modelled outdoor air pollution outside the day care centers and onset and remission of wheeze, rhinitis and eczema in the national CCHH study (Norbäck et al., 2019; Lu et al., 2021). To study health effects of outdoor air pollution was not include in the aims, but outdoor air pollution could be a potential confounder in our study. However, we did not find any associations between outdoor air pollution outside the day care centers and the proportion of children in each day care center exposed to the household environmental factors. Thus, we have no indications of confounding by outdoor air pollution. Another potential problem could be confounding by other indoor exposure in the current home environment. However, further adjustment for type of cooking fuel, air conditioner, air humidifier, air cleaner and window opening habits did not change the results. Thus, we have no indications of confounding by other indoor factors in the current home.

The study population was relatively large, but since we only included ten day care centers in the city, further studies in other parts of China are needed to replicate our findings. Selection bias can influence epidemiological studies. The day care centers were randomly selected in five representative districts in Taiyuan and the participation rate was high (74.2%). In China, most children over 3 years age (80%) attend a daycare center, and in cities the number is even higher (Norbäck et al., 2018b). Thus, selection bias related to participation bias is less likely.

Retrospective assessment of health and exposure in a questionnaire study may cause non-differential misclassification (reducing power of the study) or differential misclassification (linked to recall bias). It is common to ask for respiratory symptoms or household environment in the last 12 months in the ISAAC (e.g. Asher et al., 1995) or the ECRHS questionnaires (e.g. Norbäck et al., 2013). In our questionnaire we ask back a few years in time, not decades back. Validation studies have demonstrated good long term reliability (over several decades) for retrospective questions on early-life cat and dog keeping (Svanes et al., 2008), early-life ETS from parental smoking (Pape et al., 2019) and childhood asthma (Kuiper et al., 2018) with Cohen kappa values from 0.71–0.79. Moreover, recall bias would most likely cause a non-specific increase of all types of health associations but we got different patterns of association for different types of exposure and different exposure periods. This also suggests that our results were not severely influenced by recall bias. Moreover, since we calculated reported onset as difference in answers between two questions, the information bias issue is more complex than in a prevalence study. Based on all these considerations, we conclude that recall bias might not be a major drawback of our study. However, the cross-sectional data collection in our study makes it less conclusive with respect to causality as compared to a prospective birth cohort study.

5. Conclusion

Prenatal as well as perinatal and postnatal exposure to emissions from renovation and new furniture can be associated with reported onset of wheeze, rhinitis and eczema. Other domestic risk factors for

reported onset of these illnesses include perinatal indoor mould, mould odour, condensation on window panes, dog keeping and impaired perceived indoor air quality. There can be different critical time windows in early life for different illnesses and different indoor exposure. Longitudinal prospective studies on risk factors in China for these childhood diseases are needed. Improving the indoor environment in Chinese homes is an important issue to counteract the increase of respiratory illness and allergic diseases in the younger generations in China.

CRedit authorship contribution statement

Dan Norbäck: Conceptualization, Supervision, Methodology, Formal analysis, Funding acquisition, Writing and rewriting. **Xin Zhang:** Conceptualization, Methodology, Supervision, Investigation, Data curation, Formal analysis, Writing and Re-writing, Funding acquisition. **Tian Li:** Investigation, Data curation, Formal analysis, Writing and re-writing. **Yifei Zhang:** Data curation, Writing and Re-writing. **Zeifei Zhang:** Data curation, Writing and Re-writing. **Liu Yang:** Data curation, Writing and re-writing. **Xingyi Chen:** Data curation, Writing and Re-writing. **Zhaohua Zeng:** Data curation, Writing and Re-writing. **Chan Lu:** Data curation, Writing and Re-writing. **Zhuohui Zhao:** Methodology, Investigation, Writing and Re-writing, funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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