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Onset of respiratory symptoms among Chinese students: associations with dampness and redecoration, PM₁₀, NO₂, SO₂ and inadequate ventilation in the school

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ABSTRACT

Objective: To study onset of respiratory symptoms among students in China in relation to the school and the home environment.

Methods: A two-year prospective cohort study among 1325 students in eight schools. Air pollution was measured at baseline in the schools. Respiratory symptoms and the home environment were assessed by a questionnaire.

Results: The 2-year onset was 14.3%, 23.2%, 15.4%, 4.7% and 37.3% for wheeze, daytime attacks of breathlessness, nocturnal cough, nocturnal wheeze/breathlessness and respiratory infections, respectively. The mean concentrations of PM₁₀, SO₂, NO₂, ozone and CO₂ in the classrooms were 129 µg/m³, 68.0 µg/m³, 43.2 µg/m³, 8.6 µg/m³ and 1208 ppm, respectively. Environmental tobacco smoke (ETS), dampness/mold at home and ozone in the classroom were associated with onset of wheeze. Onset of daytime breathlessness was associated with redecoration and dampness/mold at home and CO₂ and relative air humidity (RH) in the classrooms. Dampness/mold at home, PM₁₀, CO₂ and RH in the classrooms and outdoor PM₁₀, SO₂ and NO₂ were associated with onset of nocturnal cough. Onset of nocturnal wheeze/breathlessness was associated with dampness/mold at home and RH and PM₁₀ in the classrooms. Respiratory infections were more common at higher levels of outdoor PM₁₀.

Conclusions: Air pollution (PM₁₀, ozone, SO₂ and NO₂) and inadequate ventilation flow in the classrooms (indicated by CO₂ > 1000 ppm) and ETS, dampness or mold and chemical emissions from redecoration at home can increase onset of respiratory symptoms.

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Introduction

The school environment may influence respiratory health among school children [1] but the lack of prospective school environment studies makes it difficult to draw clear conclusion on respiratory effects of the school environment [2]. We found only two prospective studies linking incidence of asthmatic symptoms to the school environment. One four-year prospective study found that cat allergen (Fel d 1), formaldehyde and mold in the classrooms increased the incidence of asthmatic symptoms among students [3]. Another two-year prospective study demonstrated that increased ventilation in the classroom reduced the incidence of asthmatic symptoms [4].

The home environment is the indoor environment where school children spend most of their time. Environmental tobacco smoke (ETS), building

dampness and indoor mold are important indoor risk factors for childhood asthma in the home environment [5,6]. Moreover, chemical emissions from indoor painting [7,8] and new furniture [9,10] can increase the risk of childhood asthma but a recent review concluded that it is not sufficient evidence to conclude that indoor painting can cause asthma [11].

In China, children are exposed to high concentrations of outdoor air pollution [12,13]. Two previous prevalence studies from China demonstrated that air pollution (NO₂, SO₂ and O₃) in the classroom or outside the school was related to asthmatic symptoms among the students [9,14]. However, we found no previous prospective study from China on associations between the school environment and respiratory symptoms.

We have performed a two-year prospective cohort study among students in randomly selected junior

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high schools in a heavily polluted city in China (Taiyuan city). The first aim was to study associations between new onset of respiratory symptoms over the two-year follow-up period and environmental factors in the home environment (ETS, dampness or mold and redecoration or new furniture). The second aim was to study associations between onset of respiratory symptoms and the school environment (CO_2 , relative air humidity (RH) and temperature) and exposure to air pollution (PM_{10} , ozone, SO_2 and NO_2) in the classroom and outside the school, adjusting for effects of the home environment. To our knowledge, this is the first prospective study from China on respiratory effects of the school environment.

Materials and methods

Study population

Taiyuan is the capital of Shanxi province, a heavily polluted city in China. Our school-based cohort study was performed in ten randomly selected junior high schools in Taiyuan. In 2010 (at baseline), we randomly selected five first year junior high school classes in each school. If the school did not have five first year classes, we selected all first year classes. Initially, 2335 first year junior high school students from 44 classes were included, and 2134 (91.4%) answered the baseline questionnaire. Two schools did not want to participate in the two-year follow-up in 2012, which included eight schools and students in 33 classrooms. All 33 classes had the same classroom during the follow-up period (from first year class to third year class) but some students had moved. Our data analysis was restricted to students having the same classroom from baseline (March 2010) to follow-up (March 2012). A total of 1325 pupils in the 33 classrooms participated in the follow-up (Figure 1). Environmental measurements, including air pollutants and indoor climate, were performed at baseline in 32 classrooms

(with 1283 participating students) and outside each school. One classroom had no environmental measurement since there was no electric power outlet. The environmental measurements were performed one to two weeks after completing the questionnaire survey.

Ethics statement

The study was approved by the Institute of High School Student Health Care in Taiyuan and the Medical Ethics Committee of Fudan University in Shanghai. All participants and parents/guardians gave informed consent. All personal information from the questionnaires was kept confidential.

Assessment of health data

The students answered a standardized questionnaire with questions on age, gender, smoking, respiratory/asthmatic symptoms, doctor diagnosis of asthma, respiratory infections, allergies and parental asthma/allergy. A history of atopy was defined as reporting pollen, cat or dog allergy. The same questionnaire was used at baseline (March 2010) and at follow-up (March 2012). The questionnaire was in Chinese and included questions from the International Study of Asthma and Allergies in Childhood (ISAAC) [15], the European Community Respiratory Health Survey (ECRHS) [16] and previous school studies from China [17], Japan [8] and Korea [18]. The questionnaires were distributed by the class teachers and were answered by the students at home together with their parents/guardians.

There were seven questions about respiratory (asthmatic) symptoms during the past 12 months asking about: (1) wheeze, (2) any daytime attack of breathlessness at rest (3), any daytime attack of breathlessness following strenuous activities, (4) dry cough at night, (5) waking up by an attacks of breathlessness,

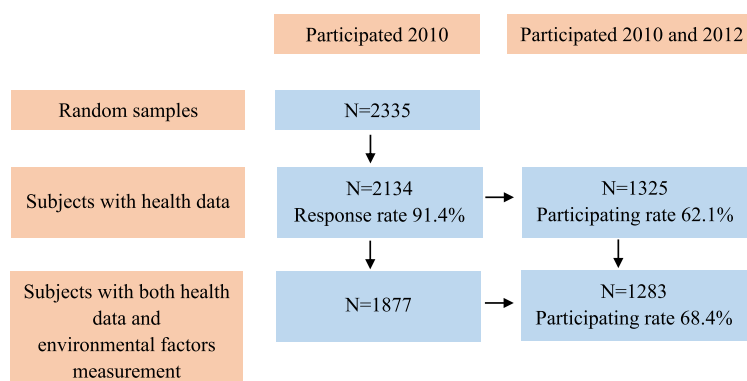


Figure 1. Selections of participants 2010 and 2012.

(6) waking up with a feeling of tightness in the chest and (7) disturbed sleep due to wheeze. Moreover, there was one question on respiratory infections (throat infections, cold or flu) in the past 3 months. All these questions were yes/no questions. A combined variable called “any daytime attacks of breathlessness” was created from the questions (2) and (3). Another combined variable “any nocturnal wheeze or breathlessness” was created from the questions (5), (6) and (7).

Assessment of self-reported home environment

There were yes/no questions on redecoration or indoor painting, dampness or mold and ETS in the current home. One dampness question asked: Have you noticed any water damage or floor dampness in your dwelling during the past 12 months? Another question asked: Have you noticed any indoor mold in your dwelling during the past 12 months? They were merged into one yes/no variable (dampness or mold at home). One question asked: Have you bought new furniture or renovated your dwelling during past 12 months? Another question asked: Have you painted your dwelling (indoor) during past 12 months? They were merged into one yes/no variable (redecoration or painting at home). The ETS question asked: Does anyone in your family smoke? Initially, we analyzed associations between the three exposure variables reported at baseline and onset of symptoms. In addition, we analyzed health association for being ever exposed at home (at baseline or follow-up) comparing with never exposed (neither at baseline nor at follow-up).

School inspection and measurement of indoor climate in the schools

We inspected the buildings and the classrooms. Details on the construction, type of ventilation system and any signs of dampness or mold were recorded. Room temperature, CO₂ and RH were measured by a direct-reading instrument (Q-TRAK IAQ monitor; TSI Incorporated, St. Paul, MN) at baseline (March 2010). Measurements were performed during normal conditions with all students present in the classroom. Moreover, temperature, CO₂ and RH were measured outside each school the same day. The instruments recorded mean levels over 1 min and were regularly calibrated.

Measurement of air pollution inside and outside the schools

The measurements were performed in March 2010. Ozone, SO₂ and NO₂ were sampled over 7 days by

diffusion samplers in the classrooms ($N=32$) and outside each school ($N=8$). The diffusion samplers were produced and analyzed by the Swedish Environmental Research Institute Ltd. (IVL) in Gothenburg, Sweden. Samplers in the classrooms were placed about 2 m above the floor. Samplers outside the schools were placed 2.5–3.5 m above the ground protected from rain. Indoor and outdoor PM₁₀ was detected by the DUSTTRAK II Aerosol monitor (TSI Incorporated) recording 1-min average values during one day in each school. The DUSTTRAK II equipment was calibrated against the nearest monitoring station which use β -Ray absorption method to measure PM₁₀. Measurements were performed in each classroom during normal conditions (full class). Outdoor measurements of PM₁₀ were performed in parallel with the indoor measurements.

Statistical methods

The prevalence of symptoms at baseline (in 2010) was compared between participants and non-participants in the two-year follow-up by Chi-square tests. Changes in the prevalence from 2010 to 2012 were calculated by the McNemar test. The onset of symptoms was calculated. As an example, onset of wheeze was defined as having current wheeze in previous 12 months at follow-up (2012) but not at baseline (2010). Initially, logistic regression models were used to calculate associations between the five respiratory symptoms and the three home environment variables adjusting for gender, age and parental allergy or asthma (one home environment variable per model). Then, we used multi-level (2-level) logistic regression models to assess associations between the symptoms and measured exposure in the school environment, adjusting for gender, age, parental allergy or asthma, redecoration/painting at home, dampness/mold at home and ETS at home. For indoor exposure, the two levels in the models were classroom and student. For outdoor exposure, the two levels were school and student. All statistical calculations were conducted by Stata 13.0 (StataCorp, CollegeStation, TX)

Results

A total of 2134 (91.4%) of the 2335 invited students in the ten schools participated in 2010. The average age was 13.7y (range 11–15y) and 50.6% were girls. Our cohort consisted of all 1325 children (62.1%) participating twice, at baseline and at follow-up. Participants and non-participants were compared with

Table 1. The prevalence of symptoms, respiratory infections and home environment exposure among junior high school students in 2010 and 2012 in Taiyuan ($N = 1325$).

Symptoms	Prevalence (%)		<i>p</i> value ^a
	2010 ($N = 1325$)	2012 ($N = 1325$)	
Girls	53.0	53.0	
Parental allergy or asthma	9.4	8.9	0.49
Doctor's diagnosed asthma	0.8	1.0	0.77
Current asthma medication	0.2	0.3	0.63
Pollen or furry pet allergy	4.3	6.8	0.001
Cat allergy	1.1	2.1	0.004
Dog allergy	0.6	0.8	0.61
Pollen allergy	3.3	4.2	0.07
Wheeze	4.3	15.0	< 0.001
Any daytime attacks of breathlessness	16.8	27.9	< 0.001
Dry cough at night	9.5	17.1	< 0.001
Any nocturnal wheeze or breathlessness	2.9	5.8	< 0.001
Respiratory infections	32.5	43.9	< 0.001
ETS at home	55.5	52.7	0.06
Redecoration or painting at home	12.0	11.8	0.91
Dampness or mold at home	20.3	23.1	0.06

^aDifference between 2010 and 2012 was analyzed by McNemar-test.

respect to baseline health data. There were no significant differences in baseline prevalence of respiratory symptoms between participants and non-participants except for a lower prevalence of daytime attacks of breathlessness among participants (16.8%) as compared to non-participants (21.5%) ($p = 0.01$). There were no significant changes of prevalence of home environment exposure from 2010 to 2012, but almost all types of symptoms had increased significantly from baseline to follow-up (Table 1). The onset rate was highest for respiratory infections (37.2%) and lowest for nocturnal wheeze or breathlessness (4.7%) (Table 2).

First, we analyzed OR for new onset symptoms and respiratory infections over the two-year follow-up in relation to home exposures at baseline. Onset of wheeze was associated with ETS (OR = 1.34; 95% CI 1.00–1.86) and dampness or mold at home (OR = 2.14; 95% CI 1.51–3.01). Onset of daytime attacks of breathlessness was associated with redecoration or painting at home (OR = 2.24; 95% CI 1.51–3.32) and dampness or mold at home (OR = 1.96; 95% CI 1.42–2.69). Onset of nocturnal dry cough (OR = 1.94; 95% CI 1.36–2.76) and nocturnal wheeze or breathlessness (OR = 2.12; 95% CI 1.21–3.72) were associated with dampness or mold at home. There were no significant associations between any home environment factors and onset of respiratory infections. Then we analyzed health associations comparing those ever exposed (2010 and/or 2012) with those never exposed. Similar significant health associations for dampness/mold and indoor painting were found as in the baseline only analysis. Moreover, there was a significant association between being ever exposed to ETS at home and nocturnal respiratory symptoms (Table 3).

Table 2. The number and percentage of two-year onset of symptoms and respiratory infections among students in 33 classes ($N = 1325$).

Symptoms	N^a	N^b	%
Wheeze	181	1268	14.3
Any daytime attacks of breathlessness	256	1103	23.2
Dry cough at night	185	1199	15.4
Any nocturnal wheeze or breathlessness	61	1286	4.7
Respiratory infections	333	895	37.2

^aNumber of students who reported the symptoms at follow-up (2012) but not at baseline (2010).

^bNumber of students who did not report the symptoms both at follow-up (2012) or at baseline (2010).

All schools were brick or concrete building without air-conditioning units or mechanical ventilation. The buildings were heated by water-born radiators. The classrooms had bare concrete floors and the students wet-mopped the floors 1–3 times per day. There were no signs of water leakage, dampness or indoor visible mold in any classrooms. Data from the exposure measurements and guideline values for the pollutants are reported in Table 4. The average indoor CO₂ concentration was 1208 ppm (range 428–2728). The average indoor temperature was 18.6 °C (range 16.0–23.0) and the mean indoor RH was 24% (range 11–44). The mean outdoor CO₂ concentration, temperature and RH were 414 ppm, 2.8 °C and 15%, respectively. The mean concentrations of PM₁₀, ozone, SO₂ and NO₂ in the classrooms were 129 µg/m³, 8.6 µg/m³, 68.0 µg/m³ and 43.2 µg/m³, respectively (Table 4).

Associations between baseline school environmental exposure and onset of respiratory symptoms were analyzed by 2-level multiple logistic regression, adjusting for personal factors and the home environment (Table 5). Onset of wheeze was associated with ozone in the classroom (OR = 1.21; 95% CI 1.00–1.46 per

Table 3. Associations between home environmental factors and new onset of symptoms and respiratory infections at baseline and at baseline or follow-up (ever vs. never exposed) among students ($N = 1325$).

Type of exposures	Wheeze (OR 95% CI)	Any daytime attacks of breathlessness (OR 95% CI)	Dry cough at night (OR 95% CI)	Any nocturnal wheeze or breathlessness (OR 95% CI)	Respiratory infections (OR 95% CI)
Baseline exposure (2010)					
ETS at home	1.34(1.00–1.86)*	0.85(0.64–1.13)	1.01(0.73–1.40)	1.54(0.89–2.67)	0.88(0.66–1.16)
Redecoration or painting at home	1.01(0.61–1.66)	2.24(1.51–3.32)***	1.10(0.67–1.81)	1.15(0.53–2.50)	0.97(0.63–1.49)
Dampness or mold at home	2.14(1.51–3.01)***	1.96(1.42–2.69)***	1.94(1.36–2.76)***	2.12(1.21–3.72)**	1.29(0.93–1.80)
Ever exposed (2010 and/or 2012) versus never exposed					
ETS at home	1.38(1.00–1.97)*	0.88(0.65–1.19)	0.90(0.64–1.26)	2.12(1.10–4.09)*	1.05(0.78–1.40)
Redecoration or painting at home	1.11(0.75–1.64)	1.53(1.10–2.15)**	0.90(0.60–1.36)	1.12(0.59–2.14)	0.90(0.64–1.27)
Dampness or mold at home	1.98(1.43–2.75)***	1.69(1.25–2.27)***	1.75(1.26–2.43)***	1.99(1.16–3.43)**	1.09(0.81–1.48)

The associations were expressed as odds ratios (OR) with a 95% confidence interval (CI) calculated by multiple logistic regression model, by adjusting for gender, age and parental asthma or allergy, analyzing each home environmental factor separately.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

Table 4. Measured indoor and outdoor climate and concentrations of air pollutants at eight schools at baseline (March 2010).

Type of exposures	N ^a	Mean $\pm$ Standard deviation	Minimum–Maximum	Guideline values ^b
Climate and air pollutants in classrooms				
Number of students	32	50 $\pm$ 8	35–65	
SO ₂ ($\mu\text{g}/\text{m}^3$)	32	68.0 $\pm$ 24.0	22.0–122.5	<20 (24-h mean)
NO ₂ ($\mu\text{g}/\text{m}^3$)	32	43.2 $\pm$ 6.6	25.5–53.3	<40 (annual mean)
O ₃ ($\mu\text{g}/\text{m}^3$)	32	8.6 $\pm$ 7.4	2.9–44.0	<100 (8-h mean)
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	32	129 $\pm$ 97	19–332	<50 (24-h mean)
Temperature ($^{\circ}\text{C}$)	32	18.6 $\pm$ 1.5	16.0–23.0	–
CO ₂ (ppm)	32	1208 $\pm$ 580	428–2728	<1000
Relative air humidity (RH%)	32	24 $\pm$ 8	11–44	–
Climate and air pollutants outside the schools				
SO ₂ ($\mu\text{g}/\text{m}^3$)	8	183.5 $\pm$ 49.5	118.5–280.1	<20 (24-h mean)
NO ₂ ($\mu\text{g}/\text{m}^3$)	8	47.5 $\pm$ 3.4	41.8–53.3	<40 (annual mean)
O ₃ ($\mu\text{g}/\text{m}^3$)	8	18.1 $\pm$ 4.5	6.0–25.0	<100 (8-h mean)
PM ₁₀ ($\mu\text{g}/\text{m}^3$)	8	168 $\pm$ 179	24–594	<50 (24-h mean)
Temperature ($^{\circ}\text{C}$)	8	2.8 $\pm$ 0.7	2.5–4.3	
CO ₂ (ppm)	8	414 $\pm$ 51	335–489	
Relative air humidity (RH%)	8	15 $\pm$ 6	6–26	

^aNumber of classrooms and schools of indoor and outdoor measurements, respectively (Only include schools with baseline measurements and two times questionnaire).

^bGuideline values for SO₂, NO₂, O₃ and PM₁₀ were obtained from the WHO (World Health Organization), and guideline values for CO₂ was obtained from the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

10 $\mu\text{g}/\text{m}^3$). Onset of daytime breathlessness was associated with CO₂ (a marker of poor ventilation) (OR = 1.54; 95% CI 1.01–2.44 per 1000 ppm) and RH (OR = 1.39; 95%CI 1.00–1.92 per 10%) in the classrooms. Onset of nocturnal dry cough was associated with indoor PM₁₀ (OR = 1.25; 95% CI 1.01–1.54 per 10 $\mu\text{g}/\text{m}^3$), CO₂ (OR = 1.79; 95% CI 1.29–2.47 per 1000 ppm) and RH (OR = 1.50; 95% CI 1.19–1.90 per 10%). Onset of nocturnal wheeze or breathlessness was associated with indoor PM₁₀ (OR = 1.41; 95% CI 1.04–1.92 per 10 $\mu\text{g}/\text{m}^3$) and RH (OR = 1.55; 95%CI 1.10–2.16 per 10%) (Table 6).

Moreover, onset of nocturnal dry cough was associated with outdoor PM₁₀ (OR = 1.19; 95% CI 1.06–1.33 per 10 $\mu\text{g}/\text{m}^3$), outdoor SO₂ (OR = 1.04; 95% CI 1.00–1.10 per 10 $\mu\text{g}/\text{m}^3$) and outdoor NO₂ (OR = 3.12;

95% CI 1.08–9.04 per 10 $\mu\text{g}/\text{m}^3$). Onset of respiratory infections was associated with outdoor PM₁₀ (OR = 1.05; 95% CI 1.00–1.24 per 10 $\mu\text{g}/\text{m}^3$).

Finally, we created mutually adjusted logistic regression models, one for each symptom, including the three co-variables (age, gender and parental asthma/allergy) and all home environment factors at baseline with p values < 0.1 in Table 3 and all classroom exposure variables except RH with p values < 0.1 in Table 5. Since RH and CO₂ had a close positive correlation, we judged CO₂ to be a more relevant variable than RH to include in the models, since it is an indicator of the personal ventilation flow and has a well-recognized guideline value (< 1000 ppm). Moreover, we did not include the outdoor air pollution levels in the mutually adjusted models since

Table 5. Associations between climate in classrooms and indoor and outdoor air pollutants in schools and two-year onset of symptoms and respiratory infections among students ($N = 1283$).

Type of exposures	Wheeze (OR 95% CI)	Any daytime attacks of breathlessness (OR 95% CI)	Dry cough at night (OR 95% CI)	Any nocturnal wheeze or breathlessness (OR 95% CI)	Respiratory infections (OR 95% CI)
Climate and air pollutants in the classrooms					
SO ₂	0.97(0.88–1.06)	0.93(0.82–1.06)	0.98(0.88–1.09)	1.03(0.89–1.21)	0.94(0.84–1.07)
NO ₂	0.83(0.61–1.11)	0.67(0.44–1.02)	0.92(0.64–1.33)	1.05(0.61–1.82)	0.89(0.58–1.36)
O ₃	1.21(1.00–1.46)*	1.13(0.80–1.59)	0.94(0.70–1.26)	0.82(0.51–1.32)	1.16(0.82–1.64)
PM ₁₀	1.15(0.91–1.44)	0.98(0.72–1.34)	1.25(1.01–1.54)*	1.41(1.04–1.92)*	1.11(0.82–1.49)
Temperature	1.00(0.86–1.17)	0.97(0.80–1.19)	1.10(0.93–1.30)	0.87(0.68–1.11)	1.08(0.90–1.29)
CO ₂	1.04(0.71–1.51)	1.54(1.01–2.44)*	1.79(1.29–2.47)***	1.34(0.79–2.30)	1.01(0.63–1.63)
RH	1.08(0.82–1.41)	1.39(1.00–1.92)*	1.50(1.19–1.90)***	1.55(1.10–2.16)**	0.94(0.67–1.30)
Air pollutants outside the school					
SO ₂	1.02(0.97–1.07)	1.02(0.94–1.10)	1.04(1.00–1.10)*	1.07(0.98–1.17)	1.03(0.95–1.10)
NO ₂	0.99(0.55–1.78)	1.07(0.42–2.73)	3.12(1.08–9.04)*	1.76(0.88–3.51)	1.15(0.48–2.80)
O ₃	0.72(0.45–1.15)	0.69(0.35–1.37)	0.81(0.45–1.45)	0.43(0.22–0.87)*	1.47(0.76–2.88)
PM ₁₀	1.07(0.94–1.22)	1.10(0.92–1.30)	1.19(1.06–1.33)**	1.17(0.99–1.39)	1.05(1.00–1.24)*

The associations were expressed as odds ratios (OR) with a 95% confidence interval (CI) of 2-level logistic regression model, by adjusting for gender, age and parental asthma or allergy and home environment (ETS at home, redecoration or painting at home and dampness or mold at home), analyzing each climate and air pollutants separately. OR refer to a step change of 10 $\mu\text{g}/\text{m}^3$, 10 $\mu\text{g}/\text{m}^3$, 10 $\mu\text{g}/\text{m}^3$, 10 $\mu\text{g}/\text{m}^3$, 1 °C, 1000 ppm and 10% of SO₂, NO₂, O₃, PM₁₀, Temperature, CO₂ and RH, respectively.

* $p < 0.05$.

** $p < 0.01$.

*** $p < 0.001$.

indoor and outdoor levels were correlated and indoor exposure in the classrooms was judged as being most important.

Onset of wheeze was more common among older children (OR 1.37; 95% CI 1.03–1.82 per year) and was associated with ozone in the classroom (OR 1.45; 95% CI 1.18–1.78 per 10 $\mu\text{g}/\text{m}^3$), PM₁₀ in the classroom (OR 1.29; 95% CI 1.05–1.60 per 10 $\mu\text{g}/\text{m}^3$) and dampness or mold at home (OR 2.17; 95% CI 1.42–3.32). Onset of daytime attacks of breathlessness was more common among girls (OR 1.47; 95% CI 1.04–2.06) and was associated with CO₂ concentration in the classroom (OR 1.53; 95% CI 1.00–2.40 per 1000 ppm), dampness or mold at home (OR 1.62; 95% CI 1.11–2.36) and redecoration or indoor painting at home (OR 2.05; 95% CI 1.27–3.33). Onset of nocturnal dry cough was associated with concentration of PM₁₀ in the classroom (OR 1.19; 95% CI 1.01–1.49 per 10 $\mu\text{g}/\text{m}^3$) and dampness or mold at home (OR 1.57; 95% CI 1.03–2.39). Onset of nocturnal wheeze or nocturnal attacks of breathlessness was less common among girls (OR 0.38; 95% CI 0.18–0.76) and was associated with PM₁₀ in the classroom (OR 1.44; 95% CI 1.05–1.99 per 10 $\mu\text{g}/\text{m}^3$). For onset of respiratory infections, none of the home environment factors or classroom exposures had a p values < 0.1 (no mutual adjustment model was created).

Discussion

We found associations between onset of respiratory symptoms and respiratory infections and factors in the

school and the home environments. Our study is one of few prospective school environment studies linking student's respiratory health to the school environment. Moreover, it is one of few prospective studies on onset of respiratory symptoms in relation to redecoration, indoor painting and new furniture at home. Mutually adjusted models confirmed that both the school environment and the home environment can influence onset of respiratory symptoms among school children.

Selection bias is an important issue. In our study, classes and schools were randomly selected. The initial participation rate was high (92%), and 62% of the students participated in the two-year follow-up. The prevalence of symptoms at baseline was mostly similar among participants and non-participants at follow-up. The participants had less daytime attacks of breathlessness, but the difference was small. Another important issue is information bias. The standardized questionnaire was identical at baseline and at follow-up. Questionnaire data on asthmatic symptoms are widely used in epidemiological research and has high specificity, but lower sensitivity. The questionnaire survey was performed one week before we performed the exposure measurements. Thus, the students answered the questionnaire without knowing the results of the school environment measurements. Moreover, there were no visible signs of mold or dampness in the classrooms, which could have caused reporting bias. One advantage with analyzing health associations for exposure at baseline, is that baseline data was reported before the reporting of onset of symptoms. This reduces the risk of reporting bias.

Table 6. Associations between measured exposure in the classrooms and home environment factors at baseline and onset of respiratory symptom among students using mutual adjusted models ($N = 1283$).

	OR (95% CI)	<i>p</i> value
Wheeze		
Age	1.37(1.03–1.82)	0.03
Girls	0.93(0.62–1.40)	0.73
Parental asthma or allergy	0.98(0.50–1.92)	0.95
O ₃	1.45(1.18–1.78)	<0.001
PM ₁₀	1.29(1.05–1.60)	0.02
ETS at home	1.06(0.71–1.60)	0.77
Dampness or mold at home	2.17(1.42–3.32)	<0.001
Any daytime attacks of breathlessness		
Age	1.00(0.79–1.27)	0.99
Girls	1.47(1.04–2.06)	0.03
Parental asthma or allergy	0.66(0.35–1.24)	0.20
CO ₂	1.53(1.00–2.40)	0.05
Dampness or mold at home	1.62(1.11–2.36)	0.01
Redecoration or painting at home	2.05(1.27–3.33)	0.003
Dry cough at night		
Age	1.19(0.91–1.57)	0.20
Girls	1.13(0.76–1.67)	0.55
Parental asthma or allergy	1.15(0.61–2.19)	0.67
PM ₁₀	1.19(1.01–1.49)	0.05
CO ₂	1.24(0.80–1.90)	0.34
Dampness or mold at home	1.57(1.03–2.39)	0.04
Any nocturnal wheeze or breathlessness		
Age	0.81(0.50–1.31)	0.39
Girls	0.38(0.18–0.76)	0.006
Parental asthma or allergy	1.51(0.56–4.05)	0.42
PM ₁₀	1.44(1.05–1.99)	0.03
CO ₂	0.88(0.69–0.46)	0.69
ETS at home	1.51(0.77–2.97)	0.23
Dampness or mold at home	1.73(0.87–3.43)	0.12

Odds ratios (OR) with 95% CI and *p* values were calculated by mutually adjusted 2-level logistic regression models including home factors in Table 3 with $p < 0.1$ and indoor air pollutants in the classrooms in Table 5 with $p < 0.1$, and the 3 co-variables (gender, age and parental asthma or allergy).

Another limitation is that the environmental measurements at school were performed only at baseline and only in heating season, but would have most likely have caused a non-differential misclassification error. Air pollution levels would most likely have been lower during non-heating season. Moreover, with baseline only exposures, recall bias is less probable. Besides, similar associations were found when considering ever exposure data from both 2010 and 2010 (ever vs. never exposed), which indicated better exposure assessment. Thus, we concluded that it is unlikely that our results were affected by selection bias or information bias. However, the limited number of schools included in the study can limit the external validity.

Respiratory symptoms were common, especially daytime attacks of breathlessness but few students had doctor's diagnosed asthma or asthma medication. This could be because existing asthma was not diagnosed or treated by a medical doctor. The low prevalence of doctor diagnosed asthma is consistent with a previous school environment study from Taiyuan [9].

We found that dampness or mold at home at baseline was associated with onset of respiratory/asthmatic symptoms. This is in agreement with the conclusions from a previous review on incidence of asthma in relation to dampness and mold at home [19]. Moreover, we found that ETS at home increased onset of wheeze, in agreement with conclusions from previous review articles on respiratory effects of ETS [5,6]. A new finding in our study is that redecoration/indoor painting/new furniture can increase the onset of daytime attacks of breathlessness. However, this is in agreement with some previous prevalence studies on this topic [7–9]. New building materials, paint and new furniture can emit formaldehyde and other volatile organic compounds (VOC) causing irritation or inflammation in the airway mucosa.

The study was performed in the end of heating season in 2010 and in 2012, and the windows in the classrooms were mostly closed. During the heating season, outdoor air pollution from coal burning is severe in Taiyuan. Exposure conditions in non-heating seasons could be different. One limitation of our school study is the short measurement time for the environmental measurements. In a previous publication, we have compared the school measurements with annual data from the local monitoring stations, as well as monitoring station data from our sampling weeks [17]. The conclusion from these comparisons was that our air pollution measurements should be fairly representative for the 2-year follow-up period. Another limitation is that we have no information on the air pollution levels outside their home. However, since junior-high school students mostly go to school located near their home, we can assume that in many cases the outdoor pollution levels are similar outside the home and outside the school.

We measured PM₁₀ in our study. Previous studies have demonstrated that particles from indoor sources in occupied classrooms are mainly larger particles [20], and thus it is relevant to measure PM₁₀ in studies on particle exposure in schools.

Indoor CO₂ concentration is an indicator of the personal ventilation flow. The mean indoor level of CO₂ was 1208 ppm. Existing ventilation standards suggests that indoor CO₂ concentration should be under 1000 ppm [21]. In our study, 63% of the classrooms did not fulfill this standard. We found that indoor CO₂ concentration was related to increased onset of daytime attacks of breathlessness and nocturnal dry cough. Our results are consistent with a previous school study from Shanghai reporting that students had a higher prevalence of current asthma symptoms

at higher levels of indoor CO₂ [14]. Moreover, one recent review concluded that student's respiratory health can be impaired at decreased ventilation rates in the classrooms [22]. Our results support the view that there should be sufficient ventilation flow in schools.

We found positive associations between indoor RH at schools and onset of daytime attacks of breathlessness, nocturnal cough and nocturnal wheeze or breathlessness. There are no clear official guideline values for indoor RH, however, as Taiyuan is in a cold climate, indoor RH is always low in winter time. Indoor RH is related to outdoor RH and indoor sources of water vapor. In classrooms, the main indoor source of water vapor is human exhaled air from the students. When ventilation flow is low, RH is increased. Our results concerning indoor RH and onset of respiratory symptoms are consistent with two previous cross-sectional school studies from Shanghai [14] and Japan [8]. In wintertime, when outdoor RH is low, indoor RH in schools is mainly an indicator of low ventilation flow.

The mean outdoor and indoor PM₁₀ concentrations were 168.0 µg/m³ and 129.0 µg/m³, respectively, 2–3 times higher than the WHO standard of 50 µg/m³ for PM₁₀ [23]. We found associations between indoor and outdoor PM₁₀ and onset of nocturnal symptoms (cough and nocturnal breathlessness/wheeze). To our knowledge, our study is the first prospective study on respiratory effects of PM₁₀ in schools. However, our result is in agreement with one study from France reporting an association between indoor PM_{2.5} in schools and the prevalence of current asthma [24]. Moreover, we found that outdoor PM₁₀ was associated with onset of respiratory infections. This is in agreement with previous studies reporting that ambient PM₁₀ is linked to common cold [25] and pneumonia among children [26,27].

In our study, the mean outdoor SO₂ concentration was 183.5 µg/m³ and the indoor concentration was 68.0 µg/m³. Outdoor SO₂ was related to onset of nocturnal cough. One previous school environment study from Taiyuan found an association between outdoor SO₂ concentrations and the prevalence of wheeze [9].

The mean outdoor and indoor NO₂ concentrations were 47.5 µg/m³ and 43.2 µg/m³, respectively, higher than the WHO annual limit value of 40 µg/m³ [23]. We found that outdoor NO₂ was related to onset of nocturnal cough. A previous study reported associations between NO₂ in the classroom and current asthma in French schools [24] and between NO₂ outside the schools and current asthma in Shanghai schools [14].

In our school study, the mean outdoor ozone concentration was 18.1 µg/m³ and the mean indoor concentration was 8.6 µg/m³. Indoor ozone was associated with onset of wheeze while outdoor ozone was negatively associated with onset of nocturnal wheeze or breathlessness. Outdoor ozone can exacerbate respiratory symptoms [28–30]. In the previous school study from Taiyuan, indoor ozone was associated with the prevalence of nocturnal attacks of breathlessness [9]. The negative association between outdoor ozone and nocturnal respiratory symptom found in our current study may be a chance finding. However, ozone is involved in reactive chemistry indoors, where ozone is consumed and more irritative chemical compounds, e.g. aldehydes, are formed [31].

Conclusions

We found associations between onset of respiratory symptoms and infections and the school and the home environments. Mutually adjusted models confirmed that both the school environment and the home environment can influence onset of respiratory symptoms among school children. Respiratory symptoms, including wheeze and attacks of breathlessness, were common and increased during follow-up. Air pollution (PM₁₀, ozone, SO₂ and NO₂) inside and outside the school and inadequate ventilation flow in the classrooms can increase the onset of respiratory symptoms among school children in China. Moreover, exposure to ETS, dampness, indoor mold and chemical emissions from redecoration, indoor painting and new furniture at home can increase the onset of symptoms. There is a need to improve the school environment and the home environment in China.

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Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Author contributions

Conceived and designed the experiments: DN XZ ZHZ. Performed the experiments: DN XZ ZHZ. Analyzed the data: CHL TL XB XZ. Contributed reagents/materials/analysis

tools: CHL TL XB DN XZ. Contributed to the writing of the manuscript: DN XZ.

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