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Rhinitis in Japanese students – associations with window pane condensation, recent indoor painting, wooden home and dog allergen at school

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ABSTRACT

We studied risk factors for rhinitis in Japanese homes and schools. A questionnaire was sent to students in four schools (12–15 y age), 1048 (99.2%) participated. Crowdedness and furry pet allergens were measured in their classrooms. Household environment data was collected by a questionnaire. Risk factors were identified by multi-level logistic regression with mutual adjustment. The prevalence of current rhinitis was 60.3%, current rhinoconjunctivitis 24.4% and weekly rhinitis 29.5%. Window condensation (AORs1.69–1.90) and indoor painting (AORs1.72–1.76) at home were associated with rhinitis. The association between painting and rhinitis was stronger in girls (interaction $p = 0.002$) and in wooden homes (interaction $p = 0.05$). Dog allergen (Can f 1) in classroom air was associated with rhinitis ($p = 0.04$). In conclusion, window pane condensation and indoor painting can be household risk factors for rhinitis and dog allergen may be a risk factor in Japanese schools. Girls can be more sensitive to emissions from indoor paint than boys.

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Rhinitis; home environment; school environment

Introduction

Rhinitis is a common respiratory illness worldwide causing impaired quality of life (Bousquet et al. 2008; Maspero et al. 2012; Cibella et al. 2015). Allergens from pollen, furry pets, house dust mites and mould can cause allergic rhinitis, which affects 10–25% of the global population (Bousquet et al. 2001). Non-allergic rhinitis is caused by weather changes, tobacco smoke and other environmental factors (Tran et al. 2011). A global study on worldwide trends in symptoms of asthma and allergies found an increase in childhood rhinoconjunctivitis, especially in Asia (Asher et al. 2006).

Japan is an industrialized country with a high prevalence of allergic rhinitis (Okubo et al. 2017). There has been an increase in allergic rhinoconjunctivitis in Japanese school children in the past decades (Futamura et al. 2011). In a large national survey performed in 2015, 26.7% of middle school children (13–15y) reported allergic rhinoconjunctivitis (Morikawa et al. 2020). Allergic rhinitis in school children is an important health issue, linked to psychosocial effects, impaired learning and asthma (Blais 2004) and reduced quality of life (Cibella et al. 2015).

In Japan, pollen from Japanese cypress (*Chamaecyparis obtusa*) and Japanese cedar (*Cryptomeria japonica*) are major outdoor allergens and house dust mites is a major indoor allergen (Nakamura et al. 2019; Yamamoto-Hanada et al. 2020). A nation-wide study of elementary school children in

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Japan found that 51% were sensitized to house dust mites and 39% to Japanese cedar pollen (Yamazaki et al. 2015). A birth cohort study found that in 2012–2014, at 9 years of age, 54.3% had specific IgE against house dust mites (Der f1) and 57.8% against Japanese cedar (Cry j 1) (Yamamoto-Hanada et al. 2020). Another study in young adults found that 78.8% were sensitized to cedar, 64.4% to cypress and 56.9% to house dust mites, measured as specific IgE (Nakamura et al. 2019). Japanese cedar and cypress pollen counts in outdoor air are associated with childhood rhinoconjunctivitis (Yoshida et al. 2013). A Japanese study found that 41.2% of young adults had pollen allergy based on reported symptoms and 22.2% had pollinosis based on doctor diagnosis (Nakamura et al. 2019).

Outdoor air pollution, climate change and household exposure can influence allergic rhinitis (Eguiluz-Gracia et al. 2020). Household factors associated with rhinitis include dampness and mould (Jaakkola et al. 2013), second hand smoke (also called ETS) (Hur et al. 2014), furry pet keeping (Bousquet et al. 2001) and dust mite allergens (Linneberg et al. 2016). A few studies have reported that condensation in window panes (Wang et al. 2014, 2014) and recent redecoration (Wang et al. 2014; Norbäck et al. 2019) could be household risk factors for rhinitis. Few studies exist on household risk factors for childhood rhinitis in Japanese students.

The indoor environment in schools can influence childhood rhinitis. One multi-center study from the European Union (EU) (Simoni et al. 2010), and a school study from China (Norbäck et al. 2019), found a higher risk of rhinitis in classrooms with poor ventilation flow, as indicated by CO₂ concentration. Moreover, PM₁₀ and relative air humidity (RH) can be classroom risk factors for rhinitis (Norbäck et al. 2019) and formaldehyde in the classrooms can increase rhinoconjunctivitis (Annesi-Maesano et al. 2012). Airborne viable mould and fungal DNA from the mould species *Aspergillus versicolor* can be other rhinitis risk factors (Simoni et al. 2011). One study from Malaysia found that the amount of fine dust (Norbäck et al. 2016) and fungal DNA in schools were associated with rhinitis (Norbäck et al. 2016). Review articles have concluded that the school environment in many countries is contaminated by cat and dog allergens, due to track in allergens from the home environment on students' clothes and hair from the home environment (Salo et al. 2009; Esty et al. 2019; Takaoka and Norbäck 2020). However, we found no previous study on associations between furry pet allergens in the classrooms and rhinitis among the students. Moreover, we found no Japanese studies on environmental risk factors for childhood rhinitis in schools.

We have performed a study in junior high schools in Japan. Data on risk factors for asthma and airway infections at home and in the schools have been published (Takaoka et al. 2017). Moreover, we have published results from the study on associations between the home and school environment and sick building syndrome (SBS) (Takaoka et al. 2016), allergies (Takaoka et al. 2016) and dermatitis (Takaoka et al. 2022). The aim of this publication was to study associations between selected household and school exposures and rhinitis, with mutual adjustment for home and school exposure.

Materials and methods

Study population

The study included all three grades of students (12–15 y) in four arbitrary selected junior high schools in Kansai region, Japan (one public and three private schools). The study was performed in a suburb of Kobe city. None of the schools had reported any health problems to the school authorities. The school children used mostly the same classroom except for sport, music and art classes. All classrooms were cleaned every day by the students after school. A total of 32 randomly selected classrooms (16 from the public school) were included. The students (n = 1056) answered a standardized questionnaire before the environment measurements (1048 students participated, 99%). The study was performed in early summer when the cedar and cypress pollen season was over in Kansai region. Kobe College's ethics committee gave approval to the study and students and parents gave informed consent.

Demographics and health data

The questionnaire has been used in school studies in Europe and Asia (Kim et al. 2005; Mi et al. 2006; Zhao et al. 2006; Norbäck et al. 2016). There were questions on age, gender, smoking, asthma and allergies (cat, dog, mould or pollen allergy).

Rhinitis symptoms

There were ISAAC questions on rhinitis and rhinoconjunctivitis (Asher et al. 2006). One yes/no question asked about nasal symptoms when not having a cold in the last 12 months (current rhinitis) with an additional question asking if these nasal symptoms were combined with eye symptoms (rhinoconjunctivitis). Moreover, one additional asked in which months the rhinitis symptoms occurred. Finally, there are two previously used standardized questions on nasal catarrh and nasal congestion in the last 3 months (Norbäck et al. 2016, 2016). As in a previous study, we defined weekly rhinitis as reporting nasal catarrh and/or nasal congestion every day or 1–4 times/week (Wang et al. 2014).

Data on outdoor air pollution

To describe the general air pollution levels in the area when the study was performed, we collected annual and monthly air pollution data for PM_{2.5}, nitrogen dioxide (NO₂) and sulphur dioxide (SO₂) from the air pollution monitoring station in Kobe city ([Air pollution data for PM2.5 in Kobe](#); [Air pollution data for NO2 in Kobe](#); [Air pollution data for SO2 in Kobe](#)). No data for ozone (O₃) was available for Kobe city.

Home environment data

There were yes/no questions on the type of building, furry pet keeping, and indoor painting in the last 12 months (Takaoka et al. 2017). Building dampness in the past 12 months was assessed by three standardized yes/no questions asked about water damage, visible mold and mould odour (Norbäck et al. 1999; Wang et al. 2019). Finally, we asked about condensation in window panes in wintertime (Wang et al. 2014, 2014; Takaoka et al. 2017). Such a condensation indicates that the relative air humidity (RH) is high and the ventilation flow is poor, especially if there is double glazing.

Crowdedness and allergen measurements in the schools

The floor area (m²) was measured in the classroom. The number of students in the class was obtained from the teacher. Crowdedness was defined as the number of students per floor area (students per m²). We vacuumed the classroom floors to collect dust in special filters, with a pore size of 6 µm (Millipore filters from ALK Abello, Copenhagen, Denmark). These measurements were performed in empty classrooms in the weekend because we were not allowed to do any measurements on weekdays. After vacuuming, we put two pairs of plastic Petri dishes in each classroom to sample airborne settling dust over 7 days.

Vacuumed dust samples were sieved, and 100 mg of dust was extracted from 2 ml of phosphate buffered saline (PBS) containing 0.05% Tween 20 (1/20 w/v) by rotating mixing for 2 h at room temperature. The liquid was then centrifuged at 4500 rpm for 10 min followed by another centrifugation of the supernatant at 10,000 rpm for 10 min. The final supernatant was transferred into a microtube and was stored in a freezer (–20°C) until allergen extraction. The extraction of allergens from the Petri dish samples was started by adding 3 ml of PBS with 1% bovine serum albumin (BSA) into the base part of the Petri-dishes. After 1 h of gentle stirring, the solution was transferred from the

base part to the lid, and left for another 1 h at room temperature. Evaporation was minimized by keeping the Petri-dish closed. The liquid was transferred to tubes and centrifuged at 7000 g for 10 min. The supernatants were stored in microtubes in a freezer (-20°C) until allergen extraction.

Cat (Fel d 1) and dog (Can f 1) and allergens were extracted from the dust extracts and analysed by ELISA using commercial kits from Indoor Biotechnologies Ltd. Allergens in vacuumed dust were reported as microgram allergen per gram dust. Allergens settled on the Petri dish surfaces were expressed as microgram allergens per total surface area of the two Petri dishes (as m^2) and per day. Details on the sampling and extraction procedures and allergen analysis have been previously published (Kim et al. 2005; Zhao et al. 2006; Takaoka et al. 2017).

Statistical methods

Group differences were analyzed by Chi² test, and correlations were calculated by a rank correlation test (Kendall's tau beta). All multivariate associations were analyzed by 3-level (school, class, student) multiple logistic regression. First we analyzed associations between reported allergies and the three rhinitis variables, adjusting for age and gender. Then, we analyzed associations between the rhinitis variables and classroom data, adjusting for gender, age, and reported atopy (one exposure per model). Age, gender and atopy can be risk factors for rhinitis, and it is common to include these demographical variables as potential confounders in multivariate models analyzing risk factors for rhinitis. As a next step, we analyzed associations between rhinitis symptoms and home environment, adjusting for age, gender and a history of atopy (one home exposure per model). Then, we studied interaction by gender and atopy, respectively, on associations between home exposure and the three rhinitis variables. Moreover, we studied the interaction between different home environment factors in associations with the rhinitis variables. In these models, we included gender, age, atopy, and home exposures with $p < 0.1$ in any of the one exposure models, and one interaction variable in each model. In the interaction analysis, a p -value < 0.1 was considered to be a significant interaction. Finally, we created mutually adjusted 3-level models by including all school exposure variables and home environment factors with $p < 0.1$ in the previous models. We calculated adjusted odds ratios (AOR) with a 95% confidence interval (CI) using STATA13.

Results

In total, 1048 students participated (99.2%). Two third (64.1%) were girls, and age of the students were 12–15 y (Mean 13.4 y; SD = 0.9). A total of 60.3% reported rhinitis in the last 12 months (current rhinitis), 24.4% rhinoconjunctivitis and 29.5% weekly rhinitis in the last 3 months. Pollen allergy was most common (25.7%) followed by cat (8.8%), dog (6.1%) and 6.0% mould allergy (6.0%). Reported atopy (32.3%) was defined as reporting at least one of these four allergies. A total of 9.3% reported more than one allergy. No gender difference in reported atopy was observed (Table 1).

In the total material ($N = 1048$), the prevalence of rhinitis was highest in March (25.7%), April (30.9%) and December (23.7%) and lowest in July (9.8%) and August (9.4%). Among those reporting pollen allergy ($N = 269$), the prevalence of rhinitis was highest in March (47.2%) and in April (56.1%). Among those without pollen allergy, the prevalence was highest in April (37.1%) and May (30.0%). Pollen allergy was linked to an elevated prevalence of rhinitis in total of 8 months, from February to May (5 months) and from August to October (3 months) (Table 2). Among students not reporting any allergy ($N = 799$), the prevalence of rhinitis was highest in December (23.6%) and lowest in August (7.5%) (data shown in text only).

Table 1. Prevalence of rhinitis and self-reported allergies, stratified by gender (N = 1048).

Type of variable	Boys (N = 371)	Girls (N = 677)	P-value	Total (N = 1048)
Rhinitis variables				
Rhinitis in the last 12 months	61.2	59.8	0.67	60.3
Rhinoconjunctivitis in the last 12 months	25.6	25.1	0.86	25.3
Weekly rhinitis in the last 3 months	32.1	28.1	0.17	29.5
Atopy ^a	31.0	33.1	0.49	32.3
Number of reported allergies				
None	69.0	66.9	0.72	67.7
One	21.6	23.8		23.0
More than one	9.4	9.3		9.3

P-values calculated by Chi-2 analysis.

^aEither self-reported cat, dog, mould or pollen allergy.

Table 2. Prevalence of seasonal rhinitis by month in different groups (N = 1048).

Month	All subjects (N = 1048) (%)	Pollen allergy (N = 269) (%)	No pollen allergy (N = 779) (%)	p-value
January	21.7	24.2	20.8	0.25
February	19.5	26.8	16.9	<0.001
March	25.7	47.2	18.2	<0.001
April	30.9	56.1	22.2	<0.001
May	18.5	29.0	14.9	<0.001
June	11.7	17.8	9.6	<0.001
July	9.8	12.6	8.9	0.07
August	9.4	12.6	8.2	0.03
September	16.0	20.8	14.4	0.01
October	20.0	25.3	18.2	0.01
November	17.2	17.1	17.2	0.97
December	23.7	22.7	24.0	0.66
Mean of all months	18.7	26.0	16.1	

P-value by 2 × 2 Chi 2 tables comparing those with and without pollen allergy.

Monitoring station data showed that the annual mean level of PM_{2.5} was 15.5 µg/m³ and monthly mean in June was 18.3 µg/m³. The annual mean level of NO₂ was 28.5 µg/m³ and monthly mean in June was 30.4 µg/m³. The annual mean level of SO₂ was 4.0 µg/m³ and monthly mean in June was 5.4 µg/m³. NO₂ and SO₂ was reported in ppb, so we converted ppb to µg/m³ by multiplying by a factor 1.9 for NO₂ and 2.7 for SO₂.

We found dog and cat allergens in almost all samples, in vacuumed dust filters and in the Petri dishes (Table 3). The mean number of students with cats in their homes per classroom was 1.4 (range 0–5) corresponding to 4.2% of the children. The mean number of students with dogs in their homes per classroom was 6.5 (range 3–15), corresponding to 19.9% of the children. Initially, we analyzed associations between the three rhinitis variables and classroom data using one exposure multilevel regression model, adjusting for age, gender and atopy (Table 4). Weekly rhinitis was positively associated with the level of airborne dog allergen (Can f1) in the classrooms ($p = 0.046$).

Most students lived in buildings made of concrete and one third (33.9%) had ETS at home. One fifth (19.9%) of the homes had dogs, while cat keeping (4.2%) and indoor painting (7.8%) were less common. The most common sign of dampness was condensation on window panes in wintertime

Table 3. Measurement data from the schools (32 classrooms).

Classroom exposure	Median (IQR)	Min-Max
Density of students (students/m ² floor area)	0.44 (0.41–0.48)	0.23–0.57
Dog allergen (Can f1) in vacuumed floor dust (ng/g)	101 (54–101)	7–536
Cat allergen (Fel d1) in vacuumed floor dust (ng/g)	41 (23–92)	2–410
Can f1 sampled on Petri dishes (ng/m ² and day)	13.3 (6.0–13.3)	<1–243.0
Fel d1 sampled on Petri dishes (ng/m ² and day)	18.6 (5.9–25.1)	<1–67.6

N = 64 (2 samples/classroom) for allergens.

Table 4. Associations between the classroom environment and rhinitis (N = 1048).

	Curent rhinitis AOR (95% CI)	<i>p</i> -value	Rhino-conjunctivitis AOR (95% CI)	<i>p</i> -value	Weekly rhinitis AOR (95% CI)	<i>p</i> -value
Student density ^c	0.93 (0.73–1.17)	0.52	0.97 (0.70–1.35)	0.70	1.18 (0.90–1.54)	0.23
Cat allergen in vacuumed floor dust ^d	0.97 (0.80–1.17)	0.76	0.94 (0.75–1.18)	0.57	1.02 (0.86–1.22)	0.80
Cat allergen in Petri dishes ^e	0.72 (0.31–1.68)	0.45	0.71 (0.22–2.26)	0.56	1.67 (0.67–4.15)	0.27
Dog allergen in vacuumed floor dust ^d	1.05 (0.92–1.21)	0.47	1.07 (0.88–1.30)	0.47	1.10 (0.96–1.25)	0.19
Dog allergen in Petri dishes ^e	0.86 (0.57–1.29)	0.46	0.78 (0.44–1.39)	0.40	1.52 (1.01–2.29)	0.046

Adjusted Odds Ratio (AOR) with 95% Confidence Interval (CI) was obtained by multilevel logistic regression models (student, room, school) including age, sex, and atopy and one school environment variable in each model.

^aAOR calculated per 1°C.

^bAOR calculated per 10% RH.

^cAOR calculated per 0.1 students/m².

^dAOR calculated per 100 ng allergen/g dust.

^eAOR calculated per 100 ng allergen/m²/day.

(38.2%). Water leakage had occurred in 7.5% of the homes, visible mold in 8.6% and mold odor in 1.3% (Table 5). As a next step, we studied associations with the home environment using multilevel logistic regression models (one exposure models) (Table 5). Rhinitis was associated with indoor mould ($p = 0.03$) and condensation on window panes ($p < 0.001$). Rhinoconjunctivitis was less common among children in wooden houses ($p = 0.04$) and more common if there was recent indoor painting ($p = 0.03$) or window pane condensation ($p = 0.001$). Weekly rhinitis was related to indoor painting ($p = 0.02$) and condensation on window panes ($p < 0.001$).

As a next step, interaction analysis was performed, to see if gender or atopy modified associations between home environment factors and the rhinitis variables. There was a significant interaction by gender on the association between recent indoor painting at home and weekly rhinitis (p -value for interaction = 0.002). In stratified analysis, AOR for indoor painting was 1.03 (95% CI 0.63–1.68) in boys and 3.22 (95% CI 1.75–5.94) in girls. Moreover, there was a significant interaction by gender on the association between living in a wooden home and current rhinitis (p -value for interaction = 0.06). In stratified analysis, AOR for wooden home was 0.81 (95% CI 0.51–1.29) in boys and 1.45 (95% CI 0.99–2.10) in girls. Atopy did not enhance any association between home environment factors and rhinitis.

Table 5. Associations between the home environment and rhinitis (N = 1048).

Type of home factor	Prevalence (%)	Current rhinitis AOR(95% CI)	<i>p</i> -value	Rhino conjunctivitis AOR(95% CI)	<i>p</i> -value	Weekly rhinitis AOR(95% CI)	<i>p</i> -value
Wooden house	29.4	1.10 (0.83–1.46)	0.50	0.70 (0.49–0.99)	0.04	1.21 (0.89–1.63)	0.22
Indoor painting last 12 months	7.8	1.58 (0.96–2.63)	0.08	1.77 (1.05–2.99)	0.03	1.82 (1.12–2.96)	0.02
Keeping dogs as pets	19.9	0.98 (0.71–1.36)	0.92	0.94 (0.64–1.39)	0.77	1.04 (0.73–1.48)	0.82
Keeping cats as pets	4.2	1.39 (0.72–2.67)	0.33	1.29 (0.62–2.72)	0.50	0.81 (0.38–1.70)	0.58
Water leakage last 12 month	7.5	1.10 (0.68–1.81)	0.68	0.98 (0.55–1.74)	0.94	1.25 (0.75–2.10)	0.38
Visible mould last 12 months	8.6	1.70 (1.05–2.76)	0.03	1.50 (0.90–2.50)	0.12	0.85 (0.51–1.42)	0.54
Window pane condensation	38.2	2.07 (1.57–2.73)	<0.001	1.71 (1.26–2.33)	0.001	1.78 (1.34–2.37)	<0.001
ETS	33.9	1.09 (0.94–1.25)	0.26	0.90 (0.76–1.07)	0.24	0.99 (0.84–1.15)	0.87

Adjusted Odds Ratio (AOR) with 95% Confidence Interval (CI) was obtained by multilevel logistic regression models (student, room, school) including age, sex, and atopy and one home environment variable in each model.

Table 6. Final models for associations between prevalence of rhinitis symptoms and personal factors, home and school exposure (N = 1048).

	AOR (95% CI)	P-value
Current rhinitis		
Girl	0.47 (0.27–0.84)	0.01
Age	1.17 (0.92–1.49)	0.20
Atopy ^a	3.19 (2.08–4.89)	<0.001
Recent painting at home	1.68 (0.83–3.42)	0.15
Visible indoor mould at home	1.56 (0.70–3.51)	0.28
Window condensation at home	1.90 (1.27–2.86)	0.002
Rhinoconjunctivitis		
Girl	0.84 (0.60–1.19)	0.33
Age	1.25 (1.03–1.53)	0.03
Atopy ^a	4.45 (3.26–6.08)	<0.001
Wooden home	0.71 (0.50–1.01)	0.06
Recent painting at home	1.72 (1.02–2.91)	0.04
Window condensation at home	1.69 (1.24–2.31)	0.001
Weekly rhinitis		
Girl	0.71 (0.52–0.99)	0.04
Age	0.95 (0.80–1.12)	0.52
Atopy ^a	2.84 (2.13–3.78)	<0.001
Can f 1 in Petri dish samples ^b	1.54 (1.02–2.32)	0.04
Recent painting at home	1.76 (1.07–2.87)	0.03
Window condensation at home	1.77 (1.33–2.35)	<0.001

Variables with $p < 0.10$ included in the 3-level multilevel models (student, room, school).

^aEither cat, dog, mould or pollen allergy.

^bOR were expressed for 100 ng/m² per day for dog (Can f 1) allergens in the Petri dish samples.

Moreover, we investigated the interaction between different home environment factors in association with the rhinitis variables. There was a significant interaction by the wooden house on the association between recent indoor painting and rhinoconjunctivitis (p -value for interaction = 0.05). In stratified analysis, AOR for indoor painting was 1.21 (95% CI 0.63–2.62) among those living in homes built by concrete and 3.80 (95% CI 1.42–10.1) among those in wooden houses. In addition, there was a significant interaction by wooden house on the association between window pane condensation and current rhinitis (p -value for interaction = 0.10). In stratified analysis, AOR for window pane condensation was 2.35 (95% CI 1.69–3.28) among those living in concrete buildings and 1.38 (95% CI 0.82–2.33) among those living in wooden buildings.

Finally, we studied associations between rhinitis and school and home environments using multilevel logistic regression models (mutual adjustment), including age, sex and atopy, and all school and home environment variables with $p < 0.1$ in Tables 4 and 5. The (mutually adjusted models) (Table 6). Rhinitis was more common in men than in women ($p = 0.01$) and was associated with atopy ($p < 0.001$) and condensation on window panes at home ($p = 0.002$). Rhinoconjunctivitis was associated with age ($p = 0.03$), atopy ($p < 0.001$), recent indoor painting at home ($p = 0.04$) and window pane condensation at home ($p = 0.001$). Weekly rhinitis was more common in boys ($p = 0.04$) and in students with atopy ($p < 0.001$), Can f1 (dog allergen) in Petri dish samples ($p = 0.04$), recent indoor painting at home ($p = 0.03$) and window pane condensation at home ($p < 0.001$).

Discussion

Rhinitis and rhinoconjunctivitis were common in the students. Dog allergen (Can f1) in the classroom air was a risk factor for weekly rhinitis symptoms. At home, environment, indoor painting and living in a home with window condensation in wintertime were associated with rhinitis or rhinoconjunctivitis. The air pollution levels in Kobe city when the study was performed were mostly below the WHO health-based standards at that time for PM_{2.5} (25 µg/m³ as 24-h

mean), NO₂ (40 µg/m³ as annual mean) and SO₂ (20 µg/m³ as 24-h mean). However, the annual mean of PM_{2.5} in Kobe city (15.5 µg/m³) was above the annual WHO guideline value for PM_{2.5} (10 µg/m³) (World Health Organization 2006).

In our study, 60.3% reported rhinitis and 24.4% rhinoconjunctivitis (ISAAC question). The prevalence of rhinoconjunctivitis was higher than the 17.6% prevalence of rhinoconjunctivitis in 13–14 y old school children in Japanese part of the ISAAC 3 repeat study (Asher et al. 2006) but similar to the 26.7% prevalence of rhinoconjunctivitis in 13–15 y old children in a large (N = 36,369) nationwide survey from 2015 (Morikawa et al. 2020). The high prevalence of rhinitis as compared to rhinoconjunctivitis may partly be due to non-allergic rhinitis.

When analyzing the question asking which months the student had rhinitis, we found that pollen allergy was a risk factor for rhinitis from February to June (5 months) and from August to October (3 months). The strongest associations were found in March and April, the peak season for cedar pollen. However, there was an elevated risk of rhinitis in relation to pollen allergy many months after the cedar pollen season, indicating that other types of pollen allergies may also play a role for allergic rhinitis in this area. Among students reporting no allergies, the highest prevalence of rhinitis was found in December. This could be due to indoor exposure to indoor allergens (e.g. house dust mite allergens) or non-allergenic triggers in the indoor environment, since the cold winter climate can lead to less ventilation of the buildings.

In the final statistical models, with mutual adjustment, the level of dog allergen (Can f1) in the classroom air, sampled by Petri dish sampling, was associated with weekly rhinitis symptoms. To our knowledge, this is a new finding, but one school environment study from Sweden reported that Can f1 concentration in vacuumed classroom dust was associated with current wheeze in elementary school children (Kim et al. 2005). Moreover, the National Health and Nutrition Examination Survey (NHANES) in USA reported that Can f1 concentration in household dust was associated with adult allergic rhinitis (Gasana et al. 2021). Besides allergens, dogs can be a source of bacteria and bacterial compounds, e.g. endotoxin (Chen et al. 2012; Tischer et al. 2015) and gram-positive bacteria (Tischer et al. 2015). Thus, tracking dog allergens from the home in the classrooms may also be linked to microbial exposure.

Allergens in indoor environments can be sampled by different methods. We used two sampling methods: vacuuming of dust from floors and collecting of settling airborne particles on empty Petri dishes. A significant association with rhinitis was found only by using Petri dish method. In a previous study in Swedish schools, we found a significant but low correlation between vacuumed dust dog allergen levels and airborne dog allergen levels measured by the Petri dish method (Spearman correlation 0.27, $p = 0.003$) (Elfman et al. 2007). Moreover, in a previous study on indoor microbiomes in student dormitories, microbial DNA was sampled by vacuuming floor dust in filters, as well as by collecting settling airborne particles on empty Petri dishes. The bacterial communities were totally different between vacuumed dust and Petri dish samples and significant associations with asthma symptoms in the students were found only for bacterial species in Petri dish samples (Fu et al. 2021). Thus, sampling of allergens and other indoor bioaerosols by the Petri dish method seems to be a useful sampling method, since it is collecting airborne particles, only.

In mutually adjusted models, recent indoor painting of the home was associated with current rhinoconjunctivitis and weekly rhinitis symptoms. Previous studies have found similar results. One review concluded that indoor painting can be a risk factor for childhood asthma and allergic diseases (Mendell 2007). Moreover, two large Chinese population studies reported that redecoration of the home increased the risk of adult rhinitis (Wang et al. 2014; Norbäck et al. 2019). Interaction analysis found that girls were more sensitive to indoor painting than boys, for weekly rhinitis. To our knowledge, this is a new finding and gender interaction for the effects of chemical indoor emissions on rhinitis should be further investigated in indoor epidemiology.

We found consistent associations between condensation on window panes during wintertime and rhinitis, rhinoconjunctivitis and weekly rhinitis symptoms. Our results are in agreement with previous population studies among adults in Sweden (Wang et al. 2014) and China (Norbäck et al. 2019; Wang et al. 2019) reporting associations between such condensation and adult rhinitis. Condensation on window panes is related to increased air concentration of volatile organic compounds (VOC), poor ventilation (Emenius et al. 2000) and house dust mite allergens (Der p1) in house dust (Luczynska et al. 1998; Emenius et al. 2000).

Traditional homes in Japan were wooden houses, but nowadays most buildings are concrete buildings. However, modern single-family houses made of wood are still common. Wooden houses are perceived as more natural and are expected to have better natural ventilation. Students living in wooden homes had less rhinoconjunctivitis, as compared to those living in concrete buildings. However, girls living in wooden houses had more rhinoconjunctivitis. Moreover, living in wooden homes seemed to modify the effect of other exposures. Interaction analysis found that those living in homes made of wood were less sensitive to the effect of window pane condensation on rhinitis as compared to those in concrete constructions. Since window pane condensation is a sign of poor ventilation flow, one explanation for this finding could be better ventilation in wooden homes. Moreover, one study from Sweden reported that wooden buildings had less fungal DNA on indoor surfaces as compared to concrete buildings (Cai et al. 2009). In contrast, interaction analysis found that those living in wooden homes were more sensitive to the effect of indoor painting on rhinitis, as compared to those living in concrete buildings. Different types of paint can emit different chemicals, and one study from Sweden reported that wooden paint in particular was associated with asthma and higher levels of formaldehyde in indoor air in homes (Wieslander et al. 1997). Thus, one explanation to our findings could be that wood paint is more commonly used for painting in wooden homes and such paints can emit more chemicals than other paints. Our findings suggest that the interaction between type of construction and indoor exposure should be further investigated in indoor epidemiology.

Our study has some strengths. To our knowledge, it is the first study on indoor environment and childhood rhinitis in Japanese schools. Moreover, almost all students (99%) participated. Thus, selection bias is less likely. Schools and classrooms were randomly selected, and schools had no history of health complaints reported to the local school authorities. Another advantage is the inclusion of data on the home and school environments in mutually adjusted models. The study was performed in early summer when the cedar and cypress pollen season was over in Kansai region. Thus, we do not expect that symptom reporting was influenced by ongoing allergic reactions to these pollens among pollen allergic children.

The study has some limitations. The number of schools and the number of students were limited. This limits the statistical power of the study, but since rhinitis is a common disease even a relatively small study can give reasonable statistical power. Outdoor air pollution is a well-known risk factor for rhinitis. We did not measure outdoor air pollution in our study, but data from the local monitoring station showed relatively low levels of outdoor air pollution in Kobe. Another limitation is that we did not measure microorganisms, VOC or airborne particles in the classrooms and that data on the home environment was assessed by the questionnaire, only. Another weakness is the lack of nasal physiological data. However, the ISAAC questions on rhinitis and rhinoconjunctivitis have been validated against doctors diagnosis and the agreement was sufficiently good (Vanna et al. 2011; Kim et al. 2012). Another limitation is that the data on IgE-mediated allergy is questionnaire data. However, high specificity (89–97%) but poorer sensitivity (28–55%) for questionnaire data on allergies have been reported, when allergy testing was the gold standard (Wieslander et al. 1997; Lakwijk et al. 1998; Linneberg et al. 2001). Thus, students reporting allergies could be expected to be sensitized. However, because of the lower sensitivity, the true prevalence of allergic sensitization could be underestimated, especially since we had no information on house dust mite allergy. Moreover, as cross-sectional study measure associations, such studies cannot be used to draw conclusions on causality.

Conclusions

Exposures at home may increase the risk of rhinitis and rhinoconjunctivitis in Japanese adolescents. Dog allergens in schools may increase the risk of rhinitis. Recent indoor painting and condensation on window panes at home can be risk factors for rhinitis. Living in a wooden house can enhance the effect of indoor painting but reduce the effect of window pane condensation on rhinitis. Girls can be more sensitive to chemical emissions from fresh indoor paint and exposures in wooden buildings. The home and the school environment in Japan could be an important issue for preventive public health measures.

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Author contributions

All authors contributed equally to the study.

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