Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 Cities Study

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ABSTRACT

Background Relationships between indoor air quality (IAQ) found in schools and the allergic and respiratory health of schoolchildren have been insufficiently explored. A survey was conducted in a large sample of classrooms of primary schools in France to provide objective assessments of IAQ to which young schoolchildren are exposed in classrooms, and to relate exposure to major air pollutants found in classrooms to asthma and allergies of schoolchildren.

Methods Concentrations of fine particles with aerodynamic diameter ≤ 2.5 μm (PM2.5), nitrogen dioxide (NO2) and three aldehydes were objectively assessed in 401 randomly chosen classrooms in 108 primary schools attended by 6590 children (mean age 10.4 years, SD ±0.7) in the French 6 Cities Study. The survey incorporated a medical visit including skin prick testing (SPT) for common allergens, a test for screening exercise-induced asthma (EIA) and a standardised health questionnaire completed by parents.

Results Children were differently exposed to poor air quality in classrooms, with almost 30% being highly exposed according to WHO standards. After adjusting for confounders, past year rhinoconjunctivitis was significantly associated with high levels of formaldehyde in classrooms (OR 1.19; 95% CI 1.04 to 1.36). Additionally, an increased prevalence of past year asthma was found in the classrooms with high levels of PM2.5 (OR 1.21; 95% CI 1.05 to 1.39), acrolein (OR 1.22; 95% CI 1.09 to 1.38) and NO2 (OR 1.18; 95% CI 0.95 to 1.41) compared with others. The relationship was observed mostly for allergic asthma as defined using SPT. A significant positive correlation was found between EIA and the levels of PM2.5 and acrolein in the same week.

Conclusions In this random sample, air quality in classrooms was poor, varied significantly among schools and cities, and was related to an increased prevalence of clinical manifestations of asthma and rhinitis in schoolchildren. Children with a background of allergies seemed at increased risk.

INTRODUCTION

Children are frail during their growth and because of their physical constitution and breathing pattern are more susceptible to the health effects of air pollution than adults. In industrialised countries, children spend more time (up to 80%) indoors, mostly in schools, than in other places except home. In the USA, data from the Environmental Protection Agency (http://nces.ed.gov/surveys/frss/publications/2000032) have shown that many schools have problems linked to poor indoor air quality (IAQ) with indoor air pollutant levels two to five times higher than outdoor levels. Indoor air pollutants can cause or contribute to short-term and long-term health problems, including nasal congestion, eye and skin irritations, coughing, sneezing, respiratory tract infection, allergic reactions, asthma, headaches, fatigue, dizziness and nausea. Moreover, indoor air pollutants can cause discomfort and reduce school attendance and productivity. However, data on air quality found in classrooms and its health effects are scant and inconsistent. Furthermore, few studies have used objective assessments of air quality and health indicators.

To bridge the knowledge gap on the health effects of air pollution in children at school, we conducted a survey in a large representative sample of classrooms in six French cities. The survey protocol was intended to provide data on IAQ in primary schools in France objectively measured in...
the frame of a field campaign, and on the relationships between
major air pollutants found in the classrooms and asthma and
rhinitis in schoolchildren using these classrooms. The air
pollutants considered included fine particles with aerodynamic
diameter ≤2.5 µm (PM2.5), nitrogen dioxide (NO2), formalde-
hyde, acetaldehyde and acrolein. In the analysis, various
cofactors were taken into account as potential confounders.

METHODS

Population and survey
The 6 Cities Study (http://www.epar.fr) aimed to investigate
the impact on childhood asthma and allergies of air pollutants
objectively assessed in different settings, including schools in six
cities (Bordeaux, Clermont-Ferrand, Créteil, Marseille, Stras-
bourg and Reims) chosen for heterogeneity of air pollution.
Study participants were children aged 9–10 years who were
invited to take part in a health survey according to a stand-
ardised protocol6–8 (for detailed information on the study
protocol, see the online data supplement). Times of school visits
for air quality assessment and medical examination of the
children were randomly chosen.

Air quality
School visits were conducted during class time in the academic
year. Concentrations of NO2, formaldehyde, acetaldehyde and
acrolein were measured with passive diffusion samplers (Radi-
ello, Padua, Italy). Concentrations of PM2.5 were measured from
Monday to Friday (night and day) using filter-based samples,
charged with a pump, from representative points of the class-
room. These measurements were made during the week when
most of the children using the classroom underwent medical
examination using standardised methodology. However, for
logistic reasons, in some children the examination was
realised beforehand or postponed. Analyses were performed in
Padua for NO2 and aldehyde samples, and in Paris for PM2.5
filters. Methods, reliability and reproducibility of air pollution
assessment have been presented elsewhere.7 9 10

Health status
Parents gave written informed consent for their children to have
a medical examination, including skin prick testing (SPT) to 10
common allergens and exercise-induced asthma (EIA) according
to the standardised protocol of the run test.7 Parents also
completed an enriched version of the International Study of
Asthma and Allergies in Childhood (ISAAC) phase II question-
naire (for details, see the online data supplement). SPT positivity
was defined as a weal at least 3 mm greater than that of the
negative control for any of the allergens, 15 min after pricking.
EIA was calculated using the formula 
\[\text{PEF}_{\text{min}} - \text{PEF}_{\text{in}}/\text{PEF}_{\text{in}} \geq 10\% \]
(PEF=peak expiratory flow).6–11 All steps of the study protocol
received approval from the French National Ethics Board.

Studied variables
For each pollutant, a 5-day mean concentration (µg/m³) in
the classroom was computed and a three-class variable of exposure
(high, medium or low) was defined with respect to the tertiles
of the concentration distribution in the classroom, independent
of the city. To investigate the impact of air quality in classrooms,
health outcomes included EIA during the period of the survey
and rhinoconjunctivitis and asthma in the past year (sneezing
and runny nose accompanied by itchy eyes out of cold in the
past year) and ‘ever had asthma’; having responded positively to
at least one of these questions, ‘wheezeing or whistling in the
chest’ or ‘wheezing or whistling in the chest at night-time’ or
‘having taken asthma treatment’ in the past year). Asthma was
classified as allergic, when accompanied by SPT positivity to at
least one allergen and non-allergic otherwise. Potential
confounders assessed through the standardised ISAAC questions
included age, gender, passive smoking, paternal or maternal
history of asthma and allergic diseases, dampness, gas appliance,
etnicity and socio-economic status (SES) coded using the
French Institut National de la Santé et des Etudes Economiques
classification (http://www.insee.fr).

Statistical and epidemiological analyses

Between-school and within-school variability (‘schools’ variance
and ‘classrooms’ variance, respectively) of the measured indoor
pollutants were estimated using linear mixed models for longi-
tudinal data (SAS MIXED procedure). Comparisons between
groups for population characteristics were made using the
Student t test for continuous variables and the Pearson χ²
test or exact Fisher test for categorical variables. Pearson corre-
lations were estimated between 5-day mean concentrations of
the various air pollutants and the prevalence of EIA assessed
during the same week of investigation. To investigate the rela-
tionship between each health outcome and each air pollutant,
a marginal model was used11 taking into account the non-
independence of data for children living in the same residential
area (as defined by the school) and sharing the same environ-
ment (climate, pollens, social factors, food products, diet
etc.). This model calculated the adjusted OR for each health
outcome at different levels of pollutant exposure. The parame-
ters of the marginal model were estimated using the generalised
estimating equation approach (SAS GENMOD) with indepen-
dent working correlation structure using the city as stratum.
These analyses were stratified using SPT positivity to
investigate the role of atopic status. Association analyses were
restricted to the subsample of schoolchildren who underwent
a medical examination in the same week as air quality assess-
ments were performed to diminish exposure misclassification
(sensitivity analysis). SAS System for AIX V.8.2 was used
for statistical analyses. A p value <0.05 indicated statistical
significance.

RESULTS

Overall, 7780 children out of 9615 who were initially selected
participated in the study. Their mean age was 10.4 years. They
originated from 401 classrooms of the 108 targeted schools in
the six cities with the questionnaire filled out by the parents
(response rate 81%). A total of 6683 school children (69%) com-
pleted the entire survey protocol. The analyses were limited
to 6590 schoolchildren for whom all the variables of interest
were available. Overall, 4643 schoolchildren underwent a
medical examination during the same week that air quality assess-
ments were performed to diminish exposure misclassification
(sensitivity analysis). SAS System for AIX V.8.2 was used
for statistical analyses. A p value <0.05 indicated statistical
significance.

Asthma and the environment

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Asthma and the environment

Air quality and health indicators
Air pollutants were variously distributed in the sample (figure 1). The lowest within-school (classrooms) variance was observed for acrolein (variance=2.55 μg/m³; SE=0.19 μg/m³; p<0.001) and the highest for formaldehyde (variance=183.52 μg/m³; SE=12.47 μg/m³; p<0.001) whereas the lowest between-school (schools) variance was observed for acrolein (variance=3.08 μg/m³; SE=0.53 μg/m³; p>0.01) and the highest for NO₂ (variance=107.26 μg/m³; SE=15.54 μg/m³; p<0.001) (for details, see the online data supplement). Overall, about one-third of the children were exposed to high concentrations of air pollutants according to standards indicated by WHO for PM₂.₅ (10 μg/m³) and NO₂ (40 μg/m³) (figure 2). In some classrooms, very high concentrations were found for formaldehyde, PM₂.₅ and NO₂.

After adjusting for confounders, rhinoconjunctivitis was more frequent in classrooms with high formaldehyde concentrations (figure 3) and asthma was more common in classrooms with high PM₂.₅ and acrolein levels (figure 4). The results are consistent after accounting for SES and ethnicity in the marginal models. Stratifying the population according to SPT positivity showed that PM₂.₅, acrolein and NO₂ were significantly related to allergic asthma (figure 5). In contrast, acrolein was negatively associated with non-allergic asthma (figure 6). Taking into account the time of year when the survey was conducted (spring and summer: 227 classrooms, 3609 schoolchildren; autumn and winter: 175 classrooms, 2981 schoolchildren), the following significant relationships were found: PM₂.₅ and asthma (OR 1.28, 95% CI 1.00 to 1.65), acrolein and asthma (OR 1.37, 95% CI 1.14 to 1.66) and PM₂.₅ and allergic asthma (OR 1.41, 95% CI 1.16 to 1.73) during the warm season; NO₂ and asthma (OR 1.18, 95% CI 1.01 to 1.59) and FA and rhinoconjunctivitis (OR 1.41, 95% CI 1.08 to 1.85) during the cold season. The sensitivity analysis confirmed previous results, although with a diminished statistical significance, probably because of the reduced sample size (data not shown). However, non-allergic asthma was found to be inversely related to acrolein (OR 0.56, 95% CI 0.29 to 0.94). The results were consistent after stratifying the restricted sample according to atopic status. Lastly, levels of PM₂.₅ and acrolein in classrooms correlated positively with the prevalence of EIA, which was assessed simultaneously (table 3).

DISCUSSION
In a random sample of primary schools, air quality in classrooms was poor and varied significantly among buildings and cities. Elevated levels of major pollutants were found to be related to a higher prevalence among schoolchildren of rhinoconjunctivitis and asthma in the year of the survey, and of EIA on the day of assessment. Children with a background of allergies were at increased risk.

In some classrooms, the mean concentrations of fine particles and NO₂ were higher than the threshold limits proposed for the control of health hazards by WHO (10 μg/m³ and 40 μg/m³ respectively). Elevated concentrations were also found for formaldehyde compared with the limits proposed by the French Agency for Environmental Safety (50 μg/m³ in the short term (2 h)), 10 μg/m³ in the long term (1 year)). Thirty per cent of schoolchildren were exposed to such elevated levels of air pollution in classrooms, which confirms previous observations. In 27 primary schools located in the city centre and suburbs of Antwerp, Belgium indoor PM₂.₅ and BTEX (benzene, toluene, ethylbenzene and xylenes) concentrations were elevated and exceeded the ambient concentrations, thus raising concerns about possible adverse health effects in susceptible children.⁹ In the cross-sectional EU-funded Health Effects of School Environment (HESE) Study conducted in five European countries, the proportions of schoolchildren highly exposed to PM₁₀ and CO₂ according to the standards for good IAQ (>50 μg/m³ and >1000 ppm, respectively) were 78% and 66%, respectively.¹⁰ This is in line with the report by the European Federation of Asthma and Allergy Associations, indicating that the right to breathe clean air in European schools is not encountered throughout Europe (http://paginas.fe.up.pt).

Table 1 Characteristics of the schoolchildren having participated in the French 6 Cities Study

<table>
<thead>
<tr>
<th>Factors</th>
<th>All (n = 6590)</th>
<th>Restricted sample (n = 4643)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years) (mean±SD)</td>
<td>10.4±0.7</td>
<td>10.4±0.7</td>
</tr>
<tr>
<td>Sex (men (%))</td>
<td>46.3</td>
<td>46.2</td>
</tr>
<tr>
<td>Weight (kg) (mean±SD)</td>
<td>36.2±8.2</td>
<td>36.3±8.2</td>
</tr>
<tr>
<td>Height (m) (mean±SD)</td>
<td>1.42±0.08</td>
<td>1.42±0.08</td>
</tr>
<tr>
<td>Body mass index (m/kg²) (mean±SD)</td>
<td>17.9±2.9</td>
<td>17.9±2.9</td>
</tr>
<tr>
<td>Peak flow (ml/min) (mean±SD)</td>
<td>330.3±49.1</td>
<td>331.7±49.6</td>
</tr>
<tr>
<td>Parental history of allergy (%)</td>
<td>36.2</td>
<td>36.6</td>
</tr>
<tr>
<td>Exposure to tobacco smoke (%)</td>
<td>43.8</td>
<td>43.0</td>
</tr>
</tbody>
</table>

*Underwent medical examination during the same week as air quality assessments.

Body mass index: weight/height².

Table 2 Prevalence rates (%) of allergic sensitisation and allergic and respiratory morbidity in the French 6 Cities Study in the entire sample population (n=6590) and in the restricted sample of children who had a clinical examination during the same week as air quality assessments (n=4643)

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>All (n = 6590)</th>
<th>Restricted sample (n = 4643)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys</td>
<td>Girls</td>
</tr>
<tr>
<td>EIA</td>
<td>9.2</td>
<td>8.3</td>
</tr>
<tr>
<td>Past year (current)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhinoconjunctivitis</td>
<td>13.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Asthma</td>
<td>9.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Allergic asthma</td>
<td>5.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Non-allergic asthma</td>
<td>2.8</td>
<td>1.8</td>
</tr>
<tr>
<td>SPT positivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All allergens</td>
<td>32.7</td>
<td>23.8</td>
</tr>
<tr>
<td>Indoor allergens</td>
<td>24.5</td>
<td>17.6</td>
</tr>
<tr>
<td>Outdoor allergens</td>
<td>14.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Moulds allergens</td>
<td>3.7</td>
<td>1.8</td>
</tr>
</tbody>
</table>

EIA, exercise-induced asthma; SPT, skin prick test.
In this study, the alarming consequence of poor air quality in classrooms was a deterioration of respiratory health. A high prevalence of asthma in the past year was found in children using classrooms with ‘high’ pollution levels of PM$_{2.5}$, NO$_2$ and acrolein. Similarly, a high prevalence of rhinoconjunctivitis in the past year was found in children using classrooms with high levels of formaldehyde. In addition, schoolchildren experienced significantly more EIA during the run test when attending classrooms with elevated levels of PM$_{2.5}$ and acrolein.

The association between air pollution in classrooms and respiratory health of schoolchildren was predictable on the basis of previous findings obtained in experimental and epidemiological settings. This suggests that there is potential for air pollution to be a contributory factor to asthma and allergies, including allergic sensitisation and morbidity in some causal sequences. However, while evidence is accumulating on the adverse impact of outdoor air pollution exposure on respiratory health, few data exist on indoor air pollution and resulting respiratory health effects, and even less in the case of school air quality. This lack of data is in spite of the fact that there is growing concern about the school environment, where children spend up to 8 h/day. Air pollutants have been found in classrooms that are known to be associated with deteriorating respiratory health in other indoor settings. In a subsample of the 6 Cities Study, exposure to acetaldehyde, toluene and formaldehyde at home was significantly associated with a higher risk of asthma. Associations between respirable dust concentrations or amount of settled dust in the classroom with asthma symptoms, new onset of self-reported pet allergy and new onset of asthma diagnoses were reported in Swedish schoolchildren. In the HESE Study, PM$_{10}$ and CO$_2$ levels in a day of normal activity (full classroom) were related to dry cough at night and rhinitis in 654 children aged 10 years and to nasal patency in the subsample having performed this clinical test. All disorders were more prevalent in children attending poorly ventilated classrooms than in others. In our study, none...
of the classrooms were mechanically ventilated, which is common in French schools where ventilation is still provided by opening windows, so comparison is not possible with other studies. In 30 classrooms in 10 naturally ventilated schools in Shanghai, indoor NO2 was associated with current asthma and asthma medication (OR 1.45 for 10\(\mu\)g/m\(^3\); \(p<0.01\)). For the first time, in our study we examined the effects of acrolein in classrooms. Interestingly, acrolein, which is a powerful irritant, was significantly associated with EIA and past year asthma. However, it cannot be excluded that acrolein is a proxy of other indoor air pollutants that were not assessed in our study.

Our study on air pollution exposure was for a limited period of time and was conducted in late childhood, therefore it does not allow clarification of the role of air pollution in the development of asthma and allergies. However, it highlights the effect that school air quality may have on asthma and rhinitis related morbidity. In our study, schoolchildren from classrooms with elevated levels of air pollutants experienced more clinical manifestations of asthma and rhinitis than others. This suggests that in the school setting, even in the absence of environmental smoking and other combustion sources, children may be equally exposed to air pollution. The fact that children attend school with associated environmental exposures early in life is also relevant because childhood is a particularly vulnerable period, when air pollution and other exposures are encountered. Other significant factors at this stage of life, but not investigated in our study, are air-pollutant-related disturbances observed in schoolchildren, such as learning impairment and poor cultural and social development. As a consequence, good air quality at school has to be maintained so as not to expose children to an increased risk of these conditions.

Our study had several limitations. Although air pollution measurements were avoided during the summer, end-of-term
and allergic sensitisation were reported by parents using the ISAAC questionnaire, which is a robust measure. Nevertheless, using these reports in the absence of objective validation could lead to misclassification of asthma and rhinitis. The definition of asthma used in this study, which combined ever asthma and current symptoms, could also have influenced the results by excluding children with asthma who were not aware of their condition because they had not received a diagnosis. However, figures for current asthma-like symptoms in the absence of ever asthma showed similar trends. Finally, due to the cross-sectional study design and the extent of air pollution measurements, our data do not allow causal relationships between air pollution and asthma and rhinitis to be established.

The strengths of our study are the sampling design, the large number of schools and classrooms, the objective assessments of various air pollutants and the sensitivity analysis, which was restricted to children for whom clinical examination and air pollution assessment were conducted simultaneously,
confirming the observed associations. Restricting the analysis to these children not only reduced exposure misclassification bias but was also appropriate to investigate short-term effects of air pollution on EIA. Although small, the significant correlations between EIA and PM$_{2.5}$ and acrolein represent an important message for public health as between 40% and 90% of people with asthma usually have EIA and could be at even higher risk when exposed to air pollution. In our population, asthma and EIA were highly related (OR 10.49, 95% CI 7.31 to 15.05).

In conclusion, poor air quality was found in randomly chosen classrooms of primary schools in metropolitan France and was related to an increased prevalence of clinical manifestations of asthma and rhinitis among schoolchildren. Whether and how exposure at school plays a role in the development of asthma and allergies needs further investigation, taking into account individual daily activity patterns.

Acknowledgements We are particularly indebted to pupils and parents without whom the study would not have been possible. We thank Yvon Le Moullac and Anne-Marie Laurent from Laboratoire d’Hygiène de la Ville de Paris, who centralised air pollution assessments and took charge of PM assessments, and Gilles Perron, Joseph Kleinepeter and Alain Target from ASPA in Strasbourg, who assessed the reproducibility of air pollution assessment. We thank David Moreau from the EPAR Department, UMR-S 707, Paris who created the database and contributed to the statistical analysis, and Soutik Banerjee from the EPAR Department, UMR-S 707, Paris who also contributed to the statistical analysis. We thank the study field team and staff at the participating air quality districts in the six cities, who helped to establish the quality of air in schools. We also thank Vincenzo Cocheo and Paolo Scarlini (Fondazione Maugeri, Italy) who helped in air pollutants assessment through passive samplers, the Education Nationale, the school doctors, school principals and teachers. We thank Professor Mercier from Comité Contre la Tuberculose et les Maladies Respiratoires, on the aegis of which the survey was conducted. Allergen extracts for skin prick testing were kindly provided by Stallergenes Laboratories (Antony, France).

Contributors IAM is the PI of the 6 Cities Study. All the authors but MH implemented the rationale of the study and conducted the survey in their city. IAM and MH conducted the statistical analysis presented in the paper. IAM wrote the paper. All the authors contributed to the study and worked on the paper.

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Competing interests None.

Patient consent obtained.

Table 3 Correlations between concentrations of air pollution and exercise-induced asthma (EIA) in the sample of children who had a clinical examination during the same week as air quality assessments (n=4643)

<table>
<thead>
<tr>
<th>Air pollutant</th>
<th>n</th>
<th>Correlation coefficient*</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_2$</td>
<td>4254</td>
<td>0.022</td>
<td>0.1555</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>4051</td>
<td>0.061</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>4374</td>
<td>−0.018</td>
<td>0.2257</td>
</tr>
<tr>
<td>Acetatedehyde</td>
<td>4374</td>
<td>−0.025</td>
<td>0.0945</td>
</tr>
<tr>
<td>Acrolein</td>
<td>3551</td>
<td>0.038</td>
<td>&lt;0.0253</td>
</tr>
</tbody>
</table>

*When less than 10 children were examined by the doctor in a classroom during a week, the median value of the concentrations of pollutants measured during the same week and the mean prevalence of EIA in the entire school were taken. NO$_2$, nitrogen dioxide; PM$_{2.5}$, fine particles with aerodynamic diameter <2.5 μm.

Ethics approval French CCPPRB.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement The 6 Cities Study should allow investigation of the relationship between stress, air pollution, asthma and allergies.

REFERENCES