Asthma and ambient air pollution in Helsinki

Antti Pönkä, Mikko Virtanen

Abstract

Objective – To study whether ambient air levels of sulphur dioxide (SO2), nitrogen dioxide (NO2), total suspended particulates (TSP), and ozone (O3) affect the number of hospital admissions for asthma.

Design – The associations between the daily number of admissions and air pollutants were analysed with Poisson regression, taking into account potential confounding factors by using the standardised protocol of the APHEA project.

Setting – Helsinki, Finland, 1987–89.

Patients and measurements – Patients admitted to hospitals through emergency rooms because of asthma (n = 2421). The daily mean concentration was 13–25 μg/m³ for SO2, 33–41 μg/m³ for NO2, 19–41 μg/m³ for O3, and 58–109 μg/m³ for TSP during the different seasons. Values are means for various stations. The daily mean temperature during the three-year period was +5.4°C (range –37–27°C).

Main results – Positive associations with admissions were observed for O3 levels in all children under 14 years, and for SO2 levels in 15–64 year olds and among those older than 64. Significant associations were also seen between admissions for digestive tract diseases (the control) and O3 levels. This suggests that the modelling, which proved to be problematic, was unsatisfactory, or it may be a statistical coincidence. A rise in temperature was associated with a low number of admissions for asthma among 0–14 year olds and among 15–64 year olds, whereas humidity did not have a significant effect on the number of admissions.

Conclusions – It is possible that even low level pollution may increase hospital admissions for asthma. However, definitive conclusions will be justified only after meta-analysis comprising several studies. The methodology was seen to have a strong effect on the results and standardised methods, possibly differing from those for the study concerning mortality, are needed to investigate the association between morbidity and ambient air pollutants.

Methods

AIR POLLUTANTS AND METEOROLOGICAL VARIABLES

The pollution parameters used were 24 hour means for SO2, NO2, and TSP, an 8 hour mean for O3, and 1 hour maximum values for SO2, NO2, and O3. The means of different stations were used for all variables except O3, which was measured at one station only.

The city of Helsinki covers a relatively small area, 185 km². The main sources of air pollutants are energy production by coal fired and oil fired power plants, road traffic, and to a small extent, industrialisation. Air pollution measurements are conducted in Helsinki by district municipal authorities. During the study period 1987–89, SO2 was measured hourly by coulometric instruments at four automatic monitoring stations, NO2 by chemiluminescence at two stations, and O3 by ultraviolet absorption at one station. The instruments are calibrated on a monthly basis for SO2 and NO2 and bimonthly for O3, and as the results are followed continuously, any disturbance in their functioning is noticed immediately. Total suspended particulates are collected by high volume samplers at six stations, at four of them every second day and at two every third day. At one weather station, measurements of temperature and relative humidity are recorded hourly. The total number of stations is eight;
four of them are situated in the centre of the
town and four in the suburbs, at heights of
2–10 m. The sites of these stations have been
selected to represent the actual exposure of the
population to ambient air pollutants.

THE MORBIDITY DATA
The data on morbidity comprise details on all
patients admitted to hospitals for asthma via
emergency wards in Helsinki in 1987–89. The
age groups 0–14 years, 15–65 years, and >64
years were analysed separately. The diagnosis
of asthma is based on the *Ninth International
Classification of Diseases* (ICD-9 code 493) is-
issued by the World Health Organization. The
number of admissions for diseases of the di-
gestive system (ICD 9 codes 520–579) was
studied similarly and used as a control. The
data concerning hospital admissions for ex-
cacerbations of asthma were obtained from the
register kept of all episodes of illnesses requiring
admission to hospital. The register contains
information on the dates of hospital stay, and
on the diagnoses and ages of the patients. The
register, its comprehensive coverage, diagnostic
criteria, and quality assessment have been de-
scribed in detail earlier. The population of
Helsinki was 488,604 in 1987, 491,148 in 1988,
and 491,777 in 1989.

MISSING VALUES
The study period comprised 1096 days. In-
formation on the concentration of TSP was
lacking for 375 days because of the sampling
strategy, and so were values for NO₂ and SO₂
for 13 and four days, respectively. However,
the frequencies of admissions during the days
with missing observations were similar to those
on the other days. Thus, the effect of the
missing observations is probably small. The
missing values were imputed from regression
analysis.

MODELLING
The variables were included in the regression
analysis in the following order: (1) long term
trend, (2) season, (3) epidemics, (4) day of
week, (5) holidays, and (6) temperature and
relative humidity. The final analysis in-
vestigating the association between average
levels of pollutants measured at different sta-
tions and admission for asthma was made by
Poisson regression analysis.

Long term trends have been controlled both
separately and jointly for each year. In addition,
yearly “dummies” have been used. Separate
terms were tested for each year. Sinusoidal
terms were introduced into the model up to
the 6th order. The combination with the best
adjusted R² was selected, including both sine
and cosine terms. In addition, different terms
for each year were tested, but found not to be
significant. Six dummy variables were formed
for the days of the week and one for holidays.
For each Christmas, a separate exponentially
decaying term—that is, exp [days from Christ-
mas]—was used.

Many attempts were made to reduce the
number of uninterpretable results. Firstly, uni-
form selection criteria for transformations were
selected for different age groups, and the effects
of the sinusoidals and differences between years
were studied. The time plots showed that the
seasonal patterns changed from year to year.
Also, it seemed clear from both the plots and
the exploratory STL (Seasonal and trend de-
composition using Loess) that the weekly pat-
terns change with time. These patterns were
modelled in many different ways, but no clear
answer was found.

The number of sinusoidal terms was origi-
ally restricted to six, but up to 19 were tried.
Different sinusoidal terms for each year were
also tried, without success. Better adjustments
were found by using different trends and espe-
cially different weekly dummies for each year.
Although the STL decomposition suggested
that the trend would differ between the days,
this was found difficult to model using standard
regression methodology. On including more
sinusoidal terms, the results became more rea-
sonable, and the opposite was also true. This
could mean that there were some exceptional
periods (heatwaves, etc) that the model was
not able to take into account. However, the
task of finding such periods proved impossible.

Another set of difficulties was encountered
when determining the proper transformations
for the pollutants. The data were rather kurtotic
—that is, most of the values did not differ much
from the mean, whereas there were some very
extreme values. These extremes tended to domi-
nate the fit if no transformations were used.
In addition, the time plots seemed rather non-
stationary. Logarithmic transformation was
therefore used. In future, generalised additive
models in addition to the STL seem to be an
attractive way of avoiding such problems.

Lags of 0, 1, and 2 days and cumulative lags
of up to 3 days were tried for the effects of all
pollutants. For those of O₃, cumulative lags up
to 5 days were tried. The lags for untransformed
values of temperature and humidity were
chosen from lags of 0, 1, and 2 days, and from
the averages of lag 0 and 1, and of lag 0, 1,
and 2 days. The lags for influenza epidemics
were chosen from lag 0 to 15 days.

Results
NUMBER OF ADMISSIONS
There were altogether 2421 admissions to hos-

tpital for asthma during the three year period—
that is, an average of 2-21 admissions daily
(table 1).

<table>
<thead>
<tr>
<th>Diagnosis and age group</th>
<th>No</th>
<th>Admissions per day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>(SD)</td>
</tr>
<tr>
<td>Asthma, all ages</td>
<td>2421</td>
<td>2·21 (1·91)</td>
</tr>
<tr>
<td>Asthma, 0–14 y</td>
<td>961</td>
<td>0·88 (1·26)</td>
</tr>
<tr>
<td>Asthma, 15–64 y</td>
<td>813</td>
<td>0·74 (1·08)</td>
</tr>
<tr>
<td>Asthma, &gt;64 y</td>
<td>647</td>
<td>0·59 (0·82)</td>
</tr>
<tr>
<td>Control*</td>
<td>9017</td>
<td>8·23 (3·63)</td>
</tr>
</tbody>
</table>

* Emergency admissions for digestive system diseases.
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Table 2 Mean values of pollutants, temperature, and relative humidity by season in Helsinki, 1987–89

<table>
<thead>
<tr>
<th>December–February</th>
<th>March–May</th>
<th>June–August</th>
<th>September–November</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂ (µg/m³)</td>
<td>26</td>
<td>22</td>
<td>13</td>
</tr>
<tr>
<td>NO₂ (µg/m³)</td>
<td>38</td>
<td>44</td>
<td>39</td>
</tr>
<tr>
<td>O₃ (µg/m³)</td>
<td>20</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>TSP (µg/m³)</td>
<td>64</td>
<td>116</td>
<td>62</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>-4°</td>
<td>+4°</td>
<td>+15°</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>89</td>
<td>79</td>
<td>75</td>
</tr>
</tbody>
</table>

Table 3 Association between the number of admissions and levels of pollutants with various lags in the Poisson regression analysis

<table>
<thead>
<tr>
<th>Disease and age group</th>
<th>Pollutant</th>
<th>Lag (d)</th>
<th>Parameter estimate (SE)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma 0–14 y</td>
<td>O₃, 8 h*</td>
<td>0</td>
<td>0.1600 (0.0778)</td>
<td>0.040</td>
</tr>
<tr>
<td>Asthma 15–64 y</td>
<td>SO₂, 24 h</td>
<td>2</td>
<td>0.2176 (0.1081)</td>
<td>0.044</td>
</tr>
<tr>
<td>Asthma 24 h</td>
<td>SO₂, 0–3</td>
<td>0–3</td>
<td>0.3086 (0.1545)</td>
<td>0.046</td>
</tr>
<tr>
<td>15–64 y</td>
<td>SO₂, 24 h</td>
<td>2</td>
<td>0.2412 (0.0956)</td>
<td>0.012</td>
</tr>
<tr>
<td>&gt;64 y</td>
<td>O₃, 8 h*</td>
<td>0</td>
<td>0.0641 (0.0282)</td>
<td>0.023</td>
</tr>
<tr>
<td>Digestive tract</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>diseases</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O₃, 8 h*</td>
<td>0–4</td>
<td>0.1152 (0.0417)</td>
<td>0.006</td>
<td></td>
</tr>
</tbody>
</table>

*One station only

Pollutants and meteorological variables
Concentrations of most pollutants in the ambient air were relatively low. The mean concentrations of SO₂, NO₂, and O₃ during the three year period, presented as arithmetic means of the values measured at the respective stations, were 19 µg/m³, 39 µg/m³, and 22 µg/m³. The mean concentration of TSP was 76 µg/m³, a high value that resulted from the meteorological conditions and the erosions of street surfaces caused by the use of studded tyres during the winter, as well as the use of sand on the streets to treat icy surfaces. Mean values of pollutants by season are given in table 2.

Relation of air pollutants to admissions
A summary of the significant associations is presented in table 3. Admissions for asthma among 0–14 year olds were related to the 8 h O₃ levels, and those among 15–64 year olds and >64 year olds to the 24 h SO₂ levels. Admissions for digestive tract disorders, which were used as a control, were significantly associated with 8 h O₃ levels, but not with other pollutants, temperature, or humidity.

Discussion
The modelling was problematic. In the first attempts, over correction for cyclicity and under correction for autocorrelation were made. Therefore, the number of sinusoidal terms was restricted from nine to six (but up to 19 were tried). Various transformations of pollution variables were tried; and finally logarithmic values were used.

The difficulties of the analysis suggest that the method of analysis may be unsatisfactory. The model was first used for analysing associations between air pollution and mortality.14 It is possible that the patterns of cyclical variation found in data for mortality and hospital admission may be different, a phenomenon that might be explained by the epidemiology associated with these outcome variables.

The results obtained here differ from those of an earlier analysis of the same data with a different methodology.1 In the earlier analysis, linear regression was used and the effect of cold was controlled with a less sophisticated method. With these methods, significant associations were observed between hospital admissions for asthma and the levels of SO₂, NO₂, O₃ and TSP.

In the present study, not only average values of pollutants measured at different stations, but also the measurements at the station with the highest values were used first in the analysis. The results of these analyses were in part illogical, showing that these measurements do not sufficiently reflect the exposure of the population to pollutants.

Hospital admissions for digestive tract disorders were significantly associated with the 8 h O₃ levels at the only station. There are two possible explanations for this illogical finding. Firstly, the modelling may be defective; if so, the association between O₃ levels and admissions due to asthma among 0–14 year olds should also be interpreted with caution. Alternatively, the apparent correlation may be a statistical coincidence.

The mean daily SO₂ values measured in Helsinki were lower than the maximum value recommended by the World Health Organization – 125 µg/m³.18 The daily guideline was not exceeded. However, a significant association was seen between daily SO₂ concentrations and the daily counts of emergency room admissions among the 15–64 year old patients and among those over 64 years old. However, this association was not observed among children. The inconsistency of the findings may suggest that there is no real effect. The other possibility is that there is a relation...
between the number of patients admitted for asthma and the presence of SO₂ at lower concentrations than previously believed harmful or than are listed in the guidelines given in many countries and by the World Health Organization. The previous study from Helsinki suggested the same among patients with chronic bronchitis.15

Although our results, using the uniform methodology of the APHEA project, suggest that even low level pollution may increase hospital admissions for asthma, no definitive conclusion can be drawn from the results without meta-analysis. The effect of methodology was seen to have a strong effect on the results and new standardised methods, possibly different from those for the study on mortality, should be developed to investigate the associations between ambient air pollutants and morbidity.

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