Effects of ambient air pollution and environmental tobacco smoke on respiratory health of non-smoking women in Hong Kong

CM Wong, ZG Hu, TH Lam, AJ Hedley and J Peters

Background Two-thirds of complaints received by the Hong Kong Environmental Protection Department in 1988 were related to poor air quality. In July 1990 legislation was implemented to reduce fuel sulphur levels. The intervention led to a reduction in respiratory symptoms and bronchial hyperresponsiveness of primary school children. The objectives of this study were to investigate the differences in respiratory health between non-smoking women living in the more polluted district (Kwai Tsing) and those living in the less polluted district (Southern); to assess the impact of the government air quality intervention; and to study the effect of environmental tobacco smoke on respiratory health in non-smoking women in both districts.

Method A total of 3405 non-smoking women, aged 36.5 years (standard deviation = 3.0), from two districts with good and poor air quality respectively before the intervention were followed yearly from 1989 to 1991. Binary latent variable modelling was used to summarize the six respiratory symptoms and to estimate the effects of risk factors.

Results In 1989, living in the polluted district was associated with poor respiratory health (odds ratio [OR] = 1.55, 95% confidence interval [CI] : 1.11–2.17, \( P < 0.01 \)). After the intervention, in the polluted district only, sulphur dioxide levels fell by up to 80% and sulphate concentrations in respirable particulates by 38%. Between 1989 and 1990–1991, there was no significantly greater decline (\( P > 0.241 \)) in the more polluted compared with the less polluted district for poor respiratory health. In 1989, the effects on poor respiratory health for exposure to two or more categories of smokers relative to none in the home (OR = 1.80, 95% CI : 1.15–2.83, \( P < 0.01 \)) were higher but not significantly than those for living in polluted relative to less polluted district (95% CI of the two effects overlapping each other).

Conclusions Environmental tobacco smoke (ETS) and outdoor air pollution had independent adverse effects on respiratory health of non-smoking women and improvement in air quality had produced some but non-significant benefits.

Keywords Air pollution, environmental tobacco smoke, respiratory health, women, Hong Kong

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The increasing number of media reports in the 1980s on the pollution of the environment in Hong Kong reflected the growing concern of people about the impact of that environment on their quality of life. In 1988, 66% of all complaints to the Hong Kong Environmental Protection Department were about air pollution. In 1989, in Kwai Tsing District, a relatively polluted area in Hong Kong, the 24-hour mean and annual mean concentrations were respectively: 350 \( \mu \text{g/m}^3 \) and 80 \( \mu \text{g/m}^3 \) for sulphur dioxide (SO\(_2\)); 260 \( \mu \text{g/m}^3 \) and 80 \( \mu \text{g/m}^3 \) for total suspended particulates (TSP); 180 \( \mu \text{g/m}^3 \) and 55 \( \mu \text{g/m}^3 \) for respirable suspended particulates (RSP); and 150 \( \mu \text{g/m}^3 \) and 80 \( \mu \text{g/m}^3 \) for nitrogen dioxide (NO\(_2\)). These concentrations exceeded the air quality objectives for air pollutants in Hong Kong.\(^1\)

Early air pollution studies showed that high concentrations in ambient air of particulates and SO\(_2\), which resulted from coal burning, were harmful to respiratory health.\(^2\) Although the concentration levels of particulates and SO\(_2\) have been reduced after implementation of legislation on air pollution in most western countries, at relatively low concentration level, they might still adversely affect human health.\(^3–6\) A review of recent
epidemiological studies concludes that respirable particulate air pollution is probably an important contributing factor in respiratory disease. The associations between particulate concentrations and mortality or hospitalizations found in European studies were not as consistent as those found in American studies, possibly due to differences in particle composition.

In adults, environmental tobacco smoke (ETS), primarily an indoor air pollutant, also has a detrimental effect upon respiratory health and was associated with higher prevalence of respiratory symptoms. Studies of non-smoking women showed that domestic exposure to ETS and gas cooking as well as coal heating increased the risk of respiratory symptoms. But no previous studies had examined the effects of ETS, outdoor air pollution and air quality intervention simultaneously.

In Hong Kong, there is a population of over 6 million living in a relatively small territory of 1070 km², where industry, housing, schools and vehicular transport are intermixed. It is inevitable that people would be exposed to the risk of ambient air pollution. Besides ETS, smoke from burning mosquito coils and incense might contribute to indoor air pollution. A study of children in Hong Kong found that ambient air pollution and ETS were significantly associated with increasing respiratory symptoms and bronchial hyperresponsiveness. This report examines the impact of both ambient air pollution and ETS upon respiratory health of non-smoking women.

Subjects and Methods

Air pollution

The Environmental Protection Department carries out 24-hour monitoring of the levels of a number of specific air pollutants: 

- SO₂, using continuous UV-fluorescence analysers (TECO43);
- NO₂ and NO, using dual channel chemiluminescence analysers (monitor 8840); and total suspended particulates (TSP) and respirable suspended particulates (RSP), using high volume samplers (Sierra-Andersen) on 3-day cycles. Air pollution control regulations prohibiting the use of fuel containing more than 0.5% by weight of sulphur were implemented in July 1990. This resulted in an immediate fall in levels of SO₂ in the most polluted areas in Hong Kong by up to 80% and initial, but unsustained declines of 18% and 23% in respirable and total particulates.

Study sample

In 1989, a population-based enquiry into the respiratory health of primary school children and their parents was set up in two districts of Hong Kong: Kwai Tsing District, a relatively polluted area and Southern District, a less polluted area. Children and their parents were recruited from primary classes three and four in 17 schools (nine in Kwai Tsing; eight in Southern). The children were sampled from schools considered to be located in constituencies which were representative of the air quality in the two districts. The same children and their parents were followed up and observed yearly in 1990 (before implementation of the air pollution control regulations) and 1991 (after implementation of the regulations). Details of the initial study design, selection of schools and classes have been reported elsewhere.

Methods of investigation

Self-completed questionnaires were developed after reference to internationally recognized standard questionnaires and used each year over the 3-year period. The parents’ questionnaire was completed at home whilst the child’s was completed in the classroom under the supervision of a trained research worker with no teacher present.

In the parents’ questionnaire, parents were asked to answer whether they had frequently experienced the following six respiratory symptoms: sore throat, morning cough, evening cough, phlegm in the morning, phlegm day or night and phlegm for 3 months.

Both children and their parents were asked to answer questions on smoking behaviour for themselves and other household members. Non-smoking mothers might live with three categories of smokers (fathers, other relatives or lodgers and children). Exposure level to ETS for non-smoking mothers was coded as 0, 1, 2 or more according to the number of smokers in the home.

In addition, parents were asked about their type of housing, their educational attainment and occupational status, type of domestic fuel used, and use of incense and mosquito coils.

Statistical methods

For the baseline year of the study in 1989, descriptive statistics, including means and standard deviations and crude prevalence rates were calculated where applicable by district for respiratory symptoms, exposure to ETS, exposure to the other sources of indoor air pollution, and sociodemographic status. χ² tests and t-tests as applicable were used to examine whether there were differences in the distributions for the variables in the two districts.

For the 1989–1991 cohort of the study, prevalence rates of respiratory symptoms, exposure to ETS and mosquito coil use were calculated by district for each of the survey years. χ² tests were used to examine whether there were differences in prevalence rates for respiratory symptoms, exposure to ETS and mosquito coil use between districts and between years.

To quantify the respiratory health status of the subjects who were observed in multiple binary outcomes (i.e. six respiratory symptoms in this study) and to estimate the risks due to various factors, a binary latent variable modelling method was employed. The method summarizes multiple binary outcomes into a binary latent variable and models the effects of explanatory factors simultaneously. This approach is equivalent to structural equation modelling for multiple continuous outcomes.

The explanatory factors including: district of residence (Kwai Tsing versus Southern); ETS exposure (lighter or heavier exposure versus non-exposure); housing type (public versus others); educational attainment (primary, lower secondary, or upper secondary or above versus no formal education); age (as a continuous variable); use of incense (yes, no); use of mosquito coils (yes, no); and type of domestic fuel (gas, other). Adjusted odds ratios (OR) with 95% confidence intervals (95% CI) and significance levels (P-values) were calculated. For the binary latent variable modelling, we assumed that real respiratory health status (normal or poor) of a subject could not be directly measured, and respiratory symptoms are manifest variables for the unobservable respiratory health. Risk factors directly affect the subject’s respiratory health with presentation of respiratory symptoms. The relationships among respiratory symptoms, unobservable respiratory health status and risk factors (covariates) are depicted in Figure 1. A Markov Chain Monte Carlo method was used for model estimation via a software package BUGS under UNIX environment. Random effects were employed to take account
of the dependence between repeated observations on the same subjects for the cohort data. Interactions between district and survey years (1990 or 1991 versus 1989) were added in the cohort data analysis in order to study the intervention effect of the low sulphur fuel regulations.

**Results**

**Crude analysis**

In the baseline year 1989, Table 1 shows that significant differences in non-smoking women's respiratory symptoms, except for evening cough ($P = 0.623$) and for phlegm in morning ($P = 0.055$), were found between the two districts with higher prevalence rates in Kwai Tsing ($P < 0.05$). Smoking among family members was more prevalent in Kwai Tsing than in Southern; and differences were observed in ETS exposure between the two districts ($P = 0.001$). There was more public housing in Kwai Tsing than in Southern ($P = 0.001$). There were more subjects with higher educational attainments in Southern than in Kwai Tsing ($P = 0.001$). More households used mosquito coils and gas for cooking in Southern than in Kwai Tsing ($P = 0.001$). No differences were found for incense use ($P = 0.131$) and non-smoking women's age ($P = 0.635$) in the two districts.

For the cohort 1989–1991, Table 2 shows that significant differences in the prevalence of respiratory symptoms, including sore throat ($P = 0.018$), phlegm day or night ($P = 0.019$) and phlegm for 3 months ($P = 0.011$) were observed between the two districts in the baseline year 1989, but in 1990 differences were only observed for phlegm for 3 months ($P = 0.044$), and in 1991 differences were not significant for all symptoms. Between the years 1989, 1990 and 1991, there was a significant decline in the prevalence of sore throat ($P = 0.002$), phlegm day or night ($P = 0.003$) and phlegm for 3 months ($P = 0.004$) in Kwai Tsing, but no significant decline was observed in Southern ($P > 0.05$). Such phenomenon indicated that there might be an effect due to implementation of the Air Pollution Control (Fuel Restriction) Regulation. The non-smoking women's exposure to ETS was in decline in the more affected Kwai Tsing ($P = 0.002$), but not in Southern which was less affected ($P = 0.198$). The number of families using mosquito coils significantly increased in Kwai Tsing ($P = 0.041$), but not in Southern ($P = 0.557$), from 1989 to 1991. Other covariates remained unchanged during the period of 1989–1991.

**Binary latent variable modelling**

In applying the binary latent variable modelling, adverse respiratory health of a subject was represented by a binary latent variable (poor 1; normal 0). We cannot observe this health measure directly. We can derive this underlying health indicator from its manifestation, i.e. respiratory symptoms, via the binary latent variable modelling. For the baseline year 1989, when the risk factors and covariates were estimated on the binary latent variable, (Table 3) the district effect was significant ($OR = 1.55$, $95\% CI : 1.11–2.17$, $P = 0.009$); lighter exposure to ETS ($ETS = 1$) was not significant ($P = 0.378$); and heavier exposure to ETS ($ETS = 2$) posed a significantly higher risk to respiratory health ($OR = 1.80$, $95\% CI : 1.15–2.83$, $P < 0.01$). Mosquito coil use was also significant ($OR = 1.58$, $95\% CI : 1.14–2.21$, $P = 0.007$). Cooking fuel type posed a higher risk for non-smoking women, but it was not significant ($OR = 2.16$, $95\% CI : 0.86–5.43$, $P = 0.101$).

For the 1989–1991 cohort, (Table 4) in Southern, there was a decrease in prevalence of the binary latent variable (a respiratory
Table 2: Prevalence rates (%) of non-smoking women's respiratory symptoms and distribution of ETS exposure and mosquito coil use by district and survey year in the cohort data

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>S&lt;sup&gt;a&lt;/sup&gt;</td>
<td>KT&lt;sup&gt;b&lt;/sup&gt;</td>
<td>P-value&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sore throat</td>
<td>5.8</td>
<td>8.1</td>
<td>0.018</td>
</tr>
<tr>
<td>Morning cough</td>
<td>2.2</td>
<td>3.1</td>
<td>0.122</td>
</tr>
<tr>
<td>Evening cough</td>
<td>2.2</td>
<td>2.6</td>
<td>0.457</td>
</tr>
<tr>
<td>Phlegm in morning</td>
<td>5.0</td>
<td>6.5</td>
<td>0.096</td>
</tr>
<tr>
<td>Phlegm day or night</td>
<td>2.9</td>
<td>4.6</td>
<td>0.019</td>
</tr>
<tr>
<td>Phlegm for 3 months</td>
<td>2.5</td>
<td>4.3</td>
<td>0.011</td>
</tr>
<tr>
<td>ETS</td>
<td>33.2</td>
<td>38.6</td>
<td></td>
</tr>
<tr>
<td>Mosquito coil use</td>
<td>25.5</td>
<td>18.0</td>
<td>0.001</td>
</tr>
</tbody>
</table>

a Southern.  b Kwai Tsing.  c P-value obtained from $\chi^2$ test for association.

Table 3: Adverse respiratory health<sup>a</sup> odds ratios (OR) and 95% confidence intervals (CI) for covariates in 1989

<table>
<thead>
<tr>
<th>Covariates</th>
<th>OR (95% CI)</th>
<th>P-value&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>District (Kwai Tsing versus Southern)</td>
<td>1.55 (1.11–2.17)</td>
<td>0.009</td>
</tr>
<tr>
<td>ETS (versus ETS = 0)</td>
<td></td>
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</tr>
<tr>
<td>ETS = 1</td>
<td>1.16 (0.83–1.62)</td>
<td>0.378</td>
</tr>
<tr>
<td>ETS = 2</td>
<td>1.80 (1.15–2.83)</td>
<td>0.010</td>
</tr>
<tr>
<td>Housing type (public versus other)</td>
<td>0.95 (0.68–1.33)</td>
<td>0.769</td>
</tr>
<tr>
<td>Educational level (versus no formal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>0.75 (0.49–1.19)</td>
<td>0.187</td>
</tr>
<tr>
<td>Lower secondary</td>
<td>0.83 (0.52–1.32)</td>
<td>0.429</td>
</tr>
<tr>
<td>Upper or post-secondary</td>
<td>0.71 (0.40–1.28)</td>
<td>0.257</td>
</tr>
<tr>
<td>Age (year)</td>
<td>1.02 (0.98–1.06)</td>
<td>0.317</td>
</tr>
<tr>
<td>Incense use (yes versus no)</td>
<td>1.26 (0.92–1.72)</td>
<td>0.151</td>
</tr>
<tr>
<td>Mosquito coil use (yes versus no)</td>
<td>1.58 (1.14–2.21)</td>
<td>0.007</td>
</tr>
<tr>
<td>Cooking fuel type (gas versus other)</td>
<td>2.16 (0.86–5.43)</td>
<td>0.101</td>
</tr>
</tbody>
</table>

<sup>a</sup> Indicated by a binary latent variable which summarized six respiratory symptoms.  <sup>b</sup> Wald $\chi^2$ test.

Discussion

After adjustment for indoor air pollution and socioeconomic factors, a significant district (air pollution) effect was found in non-smoking women. ETS exposure also showed a significant hazardous effect in non-smokers and mosquito coil use was found to be harmful to respiratory health of non-smoking women.

The end-points of respiratory health, i.e. outcome measures, in our study were non-fatal respiratory symptoms. Using logistic regression models on individual symptoms, we observed a significant district effect for sore throat (OR = 1.52, 95% CI: 1.13–2.04), morning cough (OR = 1.65, 95% CI: 1.03–2.64), phlegm in morning (OR = 1.40, 95% CI: 1.03–1.92), phlegm day or night (OR = 1.63, 95% CI: 1.10–2.42) and phlegm for 3 months (OR = 1.70, 95% CI: 1.13–2.56) in non-smoking women (results not presented). The statistical method that we used in this paper combined the two steps used in the analysis of the children’s data. First a binary latent variable was introduced to account for the six binary outcomes; and second, district main effect and covariates were included in the same model to explain the binary latent variable. When outcomes are not rare events and not strongly correlated, the method used in the children’s data analysis is less efficient. The binary latent variable modelling method used in this paper is more efficient. A common mistake of searching across models for preferred outcomes in regression modelling is also avoided.

The concentration levels of SO<sub>2</sub> and TSP in Kwai Tsing were much lower than the standards under which Holland et al. argued that an air pollution effect could not be disentangled from health effects of other factors. Nevertheless, we found that the respiratory health of non-smoking women differed between those living in Kwai Tsing and those living in Southern District. Our findings are consistent with the argument that air pollution might adversely affect human health at relatively low concentrations.

In our study, the OR for the district effect was 1.55, which is consistent with Dockery’s statement that the health effects of air pollution observed in the cities of the United States would usually be weak, with a relative risk of less than 2, and often less than 1.5 for typical exposures.

It is unlikely that the differences we observed in the respiratory health of non-smoking women between those living in Kwai Tsing and those living in Southern were due to other risk factors or different distributions of socioeconomic factors in the two study populations. Although smoking prevalence was higher in Kwai Tsing than that in Southern, approximately the...
same district effects were observed in non-smoking women unexposed to ETS and those exposed to ETS as no interaction effect was found between the district and ETS (results not presented). We noted that more parents in Kwai Tsing had lower educational attainment than those in Southern. However, there were no differences in the district effects between parents with lower educational attainment and those with higher educational attainment.

In this study, we did not consider the impact of occupational exposures because approximately two-thirds of women in this study were housewives, and over half of the employed women worked in professional and services sectors. These women should be relatively free from hazardous occupational exposures. Because of the high price of housing in Hong Kong, air quality is not a primary consideration for moving house and migration should not introduce major biases to the results of our study.

Our results showed that implementation of the air pollution control regulation appeared to have some impact on the respiratory health of women, but the effect was not statistically significant. The air pollution control regulation aimed to limit high sulphur content fuels, which were used in industrial furnaces and power plants and motor vehicle combustion (primarily diesel powered). In Hong Kong, industry, housing, schools and vehicular transport are intermixed. Fathers and children had to be exposed to the risk of air pollution (from vehicular transport and industrial exhaust) in order to go to work or school, while most mothers of the children were housewives and spent much time at home. Therefore, changes in SO2 concentrations may be more likely to affect the respiratory health of fathers and children than that of mothers. Also as the subjects are adults as well as in children,12

greater than the effects of lighter exposure to ETS, but less than those of heavier exposure to ETS indicating that heavy ETS exposure might pose higher risk to respiratory health of adults than exposure to ambient air pollution in this environment. This finding is consistent with that from the results of the children’s data.15 The similar magnitude of OR of ETS exposure for non-smoking women and children indicated that ETS exposure can also cause adverse respiratory health effects in adults as well as in children.12

We noted that the women would spend most of their time working within the home so they might be exposed to the indoor air pollution for longer periods than other family members. In addition to ETS, incense use, mosquito coil use and cooking with gas are also sources of indoor air pollution. Housing type would affect the concentration levels of indoor air pollutants. In addition to ambient air pollution, these factors might also have an impact on respiratory health of non-smoking women, thus complicating the analysis of the effects of ETS exposure. However, the estimated OR of the ETS effects changed little when compared with those produced by excluding other factors. So it is unlikely that the effects of ETS exposure observed in this study are confounded by other risk factors.

Cooking with gas appliances is associated with increased nitrogen dioxide (NO2) concentration in homes. Inconsistent associations between respiratory health and indoor air pollution from these appliances have been reported in the studies on children.30–32 However, our findings are consistent with the results of the other studies on adults.12,33 In addition, we found that mosquito coil use also increased the prevalence of respiratory symptoms in non-smoking women.14

The findings in our study were unlikely to be due to non-response bias as the response rates were 96% for the parents' questionnaires and 99% for children's questionnaires. There may be a tendency to overreporting of respiratory symptoms by subjects if they know that the study is on air pollution. In order to avoid such possible bias, the study was presented to all participants as a general health survey and all media coverage was avoided until its completion.

Misclassification of air pollution and ETS exposure might have occurred. Individual exposures to air pollution might differ substantially even within the same district. Using the location of their child’s school to measure parents’ exposure level to air pollution was a crude method. On the other hand, because Hong Kong is a relatively small territory, some people might live in one district and work in another. Such cases occurred less in women than in men because 59.1% of the 3521 mothers in 1989 were housewives. For these women, exposure to air pollution might be relatively stable, compared with their husbands, if the latter

<table>
<thead>
<tr>
<th>Year effect (Southern)</th>
<th>Year effect (Kwai Tsing)</th>
<th>District-year interaction</th>
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<tbody>
<tr>
<td>LOR (SE)</td>
<td>P-value</td>
<td>LOR (SE)</td>
</tr>
<tr>
<td>1990 versus 1989</td>
<td>-0.51 (0.28)</td>
<td>0.069</td>
</tr>
<tr>
<td>1991 versus 1989</td>
<td>-0.68 (0.30)</td>
<td>0.023</td>
</tr>
</tbody>
</table>

a. Indicated by a binary latent variable which summarized six respiratory symptoms.
b. District, ETS, housing type, educational level, age, incense use, mosquito coil use and cooking fuel type were adjusted in the model.
c. Wald χ² test.
Acknowledgements

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References