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Air pollution and PEF measurements of children in the vicinity of a steel works

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The effects of short-term changes in particulate air pollution on the respiratory health of symptomatic children living near a steel works at Raahe, Finland, were assessed to determine whether particulate air pollution is associated with adverse respiratory effects, and whether specific sources of air pollution are responsible for these effects. A screening questionnaire on respiratory symptoms was distributed to 1355 primary school children during the winter, asking about lower respiratory symptoms (wheezing, attacks of wheezing, dry cough, asthma). 56 symptomatic children (34 with asthma and 16 with dry cough) were followed up for four months with measurements of daily peak expiratory flow (PEF). The acute effects of inhalable particles (PM_{10}), fine particles ($PM_{2.5}$), elements (Al, K, Cu, Zn, SO_4^{2-}) and sulphur dioxide (SO_2) were estimated by linear first-order autoregressive model. Mean daily $PM_{2.5}$ concentrations were 10 μg m^{-3}. Most regression coefficients between air pollution and morning and evening PEF were negative but not statistically significant. There was no statistically significant association between particulate air pollution and respiratory health among these symptomatic children. The only significant association was between Cu lag 3 (three days before) and morning PEF, it is difficult to assess, the meaning of this association, because the other variables related to Cu had no significant associations with morning or evening PEF. The significance of this observation therefore requires confirmation and further investigation.

Introduction

Particulate air pollution has been associated with numerous harmful health outcomes, but the exact mechanisms are still unclear. One hypothesis is that the chemical composition of the particles plays a roll, especially in the case of transition metals (EPA 2001, Wilson *et al*. 2002).

There is consistent evidence that the levels of PM_{10} particulate matter (with an aerodynamic diameter less than 10 μm) in the air are associated with the rate of death from all causes and

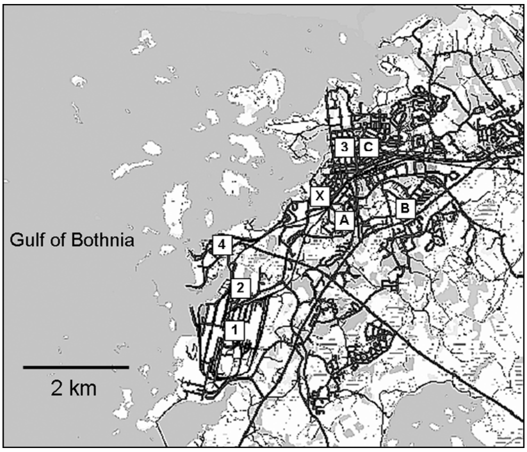

Fig. 1. The Raahe area: (1) steel works; (2) weather station of steel works; (3) town centre; (4) settled area situated closest to steel works; (A), (B), (C); schools and (X) monitoring site.

from cardiovascular and respiratory illnesses in adults or elderly people (Gold *et al*. 2000, Samet *et al*. 2000, Penttinen *et al*. 2001, Chalupa *et al*. 2004). Low levels of PM_{10} have been shown to be associated with respiratory health problems among children with asthmatic symptoms in Kuopio, Finland (Timonen *et al*. 1998), and associations between high PM_{10} concentrations and increased respiratory symptoms and use of medication among children have been found near an old integrated steel mill in Utah Valley, USA (Pope *et al*. 1991, Pope and Dockery 1992). As in Kuopio, children with chronic respiratory conditions suffered more serious acute health effects than asymptomatic children (Pope and Dockery 1992, Timonen and Pekkanen 1997).

Iron and its compounds, when present as pollutants in the atmosphere, can be deleterious to humans, animals and materials. The inhalation of iron oxide fumes or dust by workers in the metal industries may result in the deposition of iron particles in the lungs, producing an X-ray appearance resembling silicosis. Some studies concerning the urban air have shown that the iron content averages 1.6 $\mu g\ m^{-3}$ and in those studies the iron and steel industry was probably the most likely source of such emissions (Gurzau *et al*. 2003). Iron concentrations of $PM_{2.5}$ particles (with an aerodynamic diameter less than 2.5 μm) have been measured in the ambient air of the following cities: Amsterdam, the Netherlands (0.02–0.4 $\mu g\ m^{-3}$), Helsinki, Finland (0.02–0.3 $\mu g\ m^{-3}$) (Janssen *et al*. 2005) and Kuopio, Finland (0.002–2.8 $\mu g\ m^{-3}$) (Hosiokangas *et al*. 2004).

Our aim was to study the effects of short-term changes in air pollution, especially particulate air pollution, on the respiratory health of symptomatic children living near a large steel works. We also wanted to examine whether specific sources of air pollution could be shown to be responsible for the possible health effects.

Materials and methods

The Raahe area

The investigation was carried out in Raahe (64°41´N, 24°29´E, 8 m above the sea level), a town of 23 000 inhabitants in western Finland (Fig. 1). The town has the largest individual steel works in the Nordic Countries, and one of the largest in Europe, consisting of a sintering plant, two blast furnaces, a coking plant, a steel smelting plant, rolling mills, an oxygen plant and lime-burning kilns. There are also two slag heaps on the site, together with storage areas for limestone, olivine, coke, coal, scrap and iron ore concentrate. The five main $PM_{2.5}$ emission sources are the long-range transport, sintering plant at the steel works, steel smelting plant, soil and street dust, and mechanical engineering works (Oravisjärvi *et al*. 2003).

Finland has a four-season climate. During the cold period in winter (January to March) low temperatures and wind speeds may cause inversion episodes with elevated air pollution levels. The ground is usually covered with snow from November to April.

Target population

A screening questionnaire on respiratory symptoms was distributed in Raahe to 1355 primary school children aged 6 to 13 years through their schools in November 1997, to be completed by their parents. 1172 children (86%) returned the questionnaire, and a total of 126 children with chronic respiratory symptoms (67 with asthma and 59 children with cough only) were asked to participate in the study. Fifty-six of these (44%, 37 with asthma and 19 with cough only) agreed to do so and started measuring daily PEF and keeping a diary on respiratory symptoms from the beginning of January 1998. In the end 50 children (89%, 34 with asthma and 16 with cough only) had valid PEF and symptom data for more than 60% of the days, and it is these who were included in the present analyses. Thirty-two children (19 with asthma and 13 with cough only) were also characterized by vitalography. All the children were from three schools located between the centre of Raahe and the steel works and fairly close to the air pollution measurement site (Fig. 1). The protocol followed the methods used in the PEACE panel study in Kuopio, Finland (Timonen *et al*. 1998), and was approved by the Ethical Committees of the University of Kuopio and Kuopio University Hospital. Written consent was obtained from the parents of the children.

Screening questionnaire

The screening questionnaire, the same as in the PEACE study, was an adapted version of previously used questionnaires: a World Health Organization questionnaire for assessing respiratory symptoms in children and a questionnaire developed at the University of Groningen, the Netherlands, based on the American Thoracic Society questionnaire for children (Brunekreef *et al*. 1992, Brunekreef 1993, Timonen *et al*. 1997). A child was considered eligible if at least one of the following had been reported: chronic respiratory symptoms (including wheezing) in the previous 12 months, an attack of shortness of breath with wheezing in the previous 12 months, dry cough during the night (other than in connection with colds) in the previous 12 months, or doctor-diagnosed asthma at any time. The screening questionnaire contained 20 questions in total.

PEF measurements and symptom diaries

The children were followed for up to 3.5 months in the winter of 1998. Acute changes in respiratory health were measured in terms of changes in peak expiratory flow (PEF). The children measured their PEF rate three times every morning (06:30–10:00) and every evening (18:00–21:00) with a Spira Peak Flow Meter (Spira Oy, Finland) while in a sitting position, before eating any food or taking any respiratory medication. All three PEF readings were noted in a diary, and the highest of the three in each case was used for the analyses (Brunekreef 1993, Timonen and Pekkanen 1997).

The children also kept a daily diary on respiratory symptoms, with help from their parents. The following symptoms were reported: cough, phlegm, runny or stuffy nose, breathing problems on waking, shortness of breath, wheezing, attacks of shortness of breath with wheezing, fever, eye irritation and sore throats. At the beginning of the study a group of asthma nurses advised the children and their parents on how the use a PEF meter and keep the necessary diary.

Vitalography

The children with respiratory symptoms were also characterized by vitalography (Vitalograph-Alpha, program no. 60.251). The children were in a standing position and were using a nose clip. The largest values for forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were selected from a minimum of three valid expiratory recordings.

Air pollution and weather data

Daily concentrations of $PM_{2.5}$ and PM_{10} particles and sulphur dioxide (SO_2) and the reflectance of $PM_{2.5}$ filters were monitored and the concentrations of 31 elements in the $PM_{2.5}$ filters analysed. The filters were analysed at the Chemical Laboratory of the Geological Survey of Finland using an inductively coupled plasma mass spectrometer (ICP-MS). The air pollution monitoring site was situated between the steel works and the centre of Raahe, 24 metres from the nearest street. The average daily volume of traffic on the streets was quite low, about 4000–5000 vehicles. Detailed descriptions of the sampling, analyses and quality control procedures have been presented in a recent paper (Oravisjärvi *et al*. 2003).

Meteorological parameters (wind speed, wind direction, temperature, air pressure and humidity) were monitored by the municipal weather station located at the same site, and data from a nearby weather station belonging to the steel works were also used (Fig. 1). Mean values of the parameters for 24 hours were calculated from the one-hour mean readings. Daily pollen counts collected with a Burkard volumetric pollen trap were obtained from the Finnish Aerobiology Group (Anon. 1998), the nearest sampler for which was located in the city of Oulu, about 75 km from Raahe and also on the coast.

Monitoring period

The monitoring period, from mid-winter to early spring, was chosen because the snow on the ground blocks out soil as an emission source, and also enables both the pollen season and the dust episodes that occur in subarctic regions every spring to be avoided. Ambient air measurements and PEF measurements were started on 8 January and ended on 19 April 1998. To allow for learning effects in the PEF measurements, the analyses were started only on 14 January. Days when a child had been out of the Raahe area for more than eight hours and days when a child's largest PEF reading was more than 40% above the same child's mean value were excluded. The period included an influenza epidemic which lasted from 16 February to 15 March 1998, and information on this was obtained from the infectious disease register of the National Public Health Institute and the City of Helsinki Health Department.

Statistical methods

The daily mean PEF deviation was calculated for the morning and evening PEF by first calculating a mean morning and evening PEF value for each child and then subtracting this from each of child's daily morning and evening PEF values. These daily PEF deviations were then averaged to obtain the daily mean deviation of morning and evening PEF in the panel. Associations between daily mean PEF deviations and air pollutants were analysed with a linear first-order autoregressive model, taking the time trend, relative humidity, temperature, influenza epidemic and holidays as potential confounders. The day of study and the day of study squared were used to model the long-term time trend. The relative humidity and temperature figures used in the analyses were the averages for the previous day (lag 1).

The concentrations of airborne pollutants during the last 24 hours (lag 0), on the previous day (lag 1), two days before (lag 2), three days before (lag 3) and four days before (lag 4), as well as the average concentrations during the four previous days (D 4), were added to the model one at a time. The airborne pollutants considered were $PM_{2.5}$, PM_{10}, reflectance of the $PM_{2.5}$ filters, SO_4^{2-} and the elements Fe, Al, Cu, K and Zn. The last four of these elements and SO_4^{2-} had been found to be markers of the main sources of pollution in the urban air of Raahe (Oravisjärvi *et al*. 2003). The statistical analyses were performed using SPSS/PC+ 5.0 software (Norušis 1992).

Results

Temperature and air pollutant concentrations

The monthly average temperatures in Raahe were –6.5 °C in January 1998, –10.7 °C in February, –6.1 °C in March and –4.1 °C in April. The coldest daily-average temperature, –22.8 °C, was measured on 4 and 16 February, and the lowest hourly-minimum temperature, –26.4 °C, was observed on 16 February (Fig. 2).

The $PM_{2.5}$ concentration varied from 2.4 to 30 $\mu g\ m^{-3}$ with a mean of 10.1 $\mu g\ m^{-3}$, while the respective values for the PM_{10} concentration were 1.2 to 79.3 $\mu g\ m^{-3}$ and 16.5 $\mu g\ m^{-3}$. The daily-mean SO_2 concentration was 4.5 $\mu g\ m^{-3}$ and it varied from 0.1 to 29.1 $\mu g\ m^{-3}$ (Fig. 2).

Questionnaire on respiratory symptoms

The prevalence of a doctor's diagnosis of asthma at any time among the primary school children was 5.7% (Table 1), 5.5% were reported to have

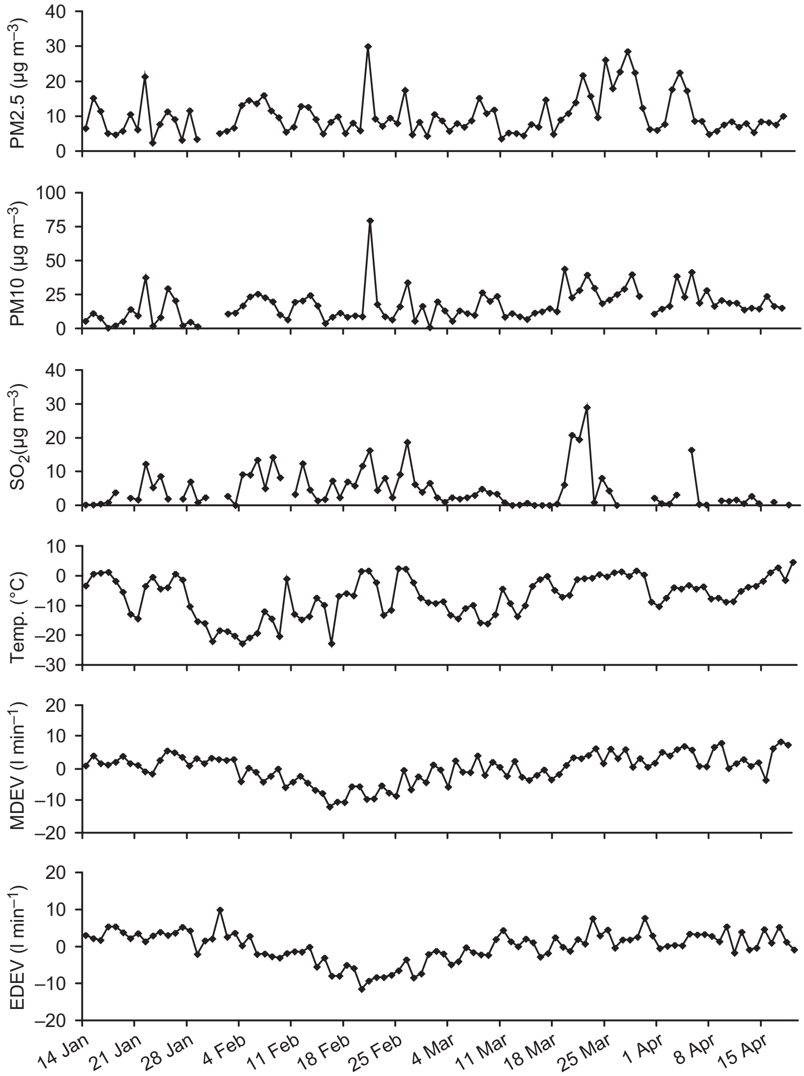

Fig. 2. Daily levels of $PM_{2.5}$ (µg m^{-3}), PM_{10} (µg m^{-3}), SO_2 (µg m^{-3}), temperature (°C) and mean daily deviation in morning (MDEV) and evening (EDEV) peak expiratory flow rate (l min^{-1}) during the period (14 Jan.–19 Apr. 1998).

had wheezing and 4.3% shortness of breath with wheezing during the past 12 months and 14% had had a dry nocturnal cough within the same period. Boys were more often reported to have chronic respiratory symptoms than girls.

PEF and air pollution

The influenza epidemic that lasted from 6 February to 15 March 1998 somewhat reduced the morning and evening PEF values (Fig. 2).

Most of the regression coefficients for morning and evening PEF with $PM_{2.5}$ and PM_{10} were negative but not statistically significant (Table 2). Similarly, no significant associations were found between PEF and the reflectance of the $PM_{2.5}$ filters (Table 2). There was no clear pattern in the associations between respiratory symptoms and Fe (Table 3).

PEF and source markers

No significant associations were found between respiratory symptoms or PEF and the concentrations of the source markers used as exposure estimates, i.e. Al, K, Cu, Zn and SO_4^{2-} (Table 3), except in the case of Cu (lag 3), for which morning PEF showed a statistically significant

Table 1. Prevalences of doctor-diagnosed asthma and chronic respiratory symptoms among 6–13-year-old school children in Raahe.

	Girls (*n* = 572) (%)	Boys (*n* = 600) (%)	All (*n* = 1172) (%)
Doctor-diagnosed asthma	3.8	7.5	5.7
Wheezing during the last 12 months	5.6	5.3	5.5
Shortness of breath with wheezing, during the last 12 months	3.3	5.2	4.3
Any of the above three findings	7.7	10	9.0
Dry cough at night, during the last 12 months	14	14	14
Any of the above four findings	17	19	18

association. It is difficult to assess the meaning of this association, however, as there were no significant association between morning or evening PEF and any of the other Cu variables (lag 1, lag 2, lag 4 or D 4). Also, the regression coefficient with Cu (lag 3) was positive whereas all the others were negative.

Table 2. Adjusted[1)] associations of morning or evening PEF deviations among children with chronic respiratory symptoms with 24-hour levels of air pollutants ($PM_{2.5}$, PM_{10} and reflectance).

	n	Morning PEF		Evening PEF	
		r	SE	*r*	SE
$PM_{2.5}$					
Lag 0	93			–0.004	0.023
Lag 1	93	–0.040	0.061	–0.001	0.024
Lag 2	92	0.029	0.063	0.019	0.024
Lag 3	91	–0.020	0.063	–0.009	0.026
Lag 4	90	–0.062	0.061	–0.006	0.027
D 4	87	–0.143	0.156	0.030	0.079
PM_{10}					
Lag 0	90			–0.013	0.056
Lag 1	90	–0.036	0.029	–0.005	0.053
Lag 2	90	0.020	0.028	0.066	0.054
Lag 3	89	–0.008	0.028	–0.005	0.058
Lag 4	88	–0.034	0.029	–0.002	0.058
D 4	81	–0.113	0.091	0.077	0.137
Reflectance					
Lag 0	92			5950	47000
Lag 1	92	–36300	56300	–10100	48700
Lag 2	91	19300	54600	58000	47400
Lag 3	90	10600	56800	26600	52600
Lag 4	89	–15800	54500	27800	51100
D 4	86	–39800	162000	210000	136000

[1)] Adjusted for time trend, relative humidity, temperature, influenza epidemic, holidays and autocorrelation. One pollutant was included in the model at a time.

Vitalography

Thirty-two of the children with respiratory symptoms were also characterized by vitalography. The mean (SD) values for the vitalographic lung function parameters were FVC 2.40 (0.82) L and FEV_1 2.06 (0.66) L among the children with asthmatic symptoms and 2.38 (0.60) L and FEV_1 2.01 (0.43) L among the children with dry cough only (Table 4).

Discussion

The aim of this work was to investigate the effects of short-term changes in air pollution on the respiratory health of children living near a large steel factory. We specifically wanted to examine which sources of air pollution could be shown to be responsible for the health effects.

Children with chronic respiratory symptoms were selected for this study on the basis of previous knowledge that symptomatic children might be more susceptible to the effects of air pollution than healthy children (Pope and Dockery 1992, Timonen and Pekkanen 1997, Boezen *et al.* 1999). All the children included to the study had chronic respiratory symptoms. This is in accordance with the result that their average pulmonary function measured by vitalography was under 100% from the predicted values. We used the same methods as in the PEACE study in Kuopio, Finland, and the study was conducted over the same time scale. An association of respiratory health problems with particulate air pollution was found among children with asthmatic symptoms in Kuopio (Timonen *et al.* 1998).

The prevalence of a doctor's diagnosis

asthma at any time was 5.7% among these primary school children, the boys more often being reported to have chronic respiratory symptoms than the girls. This is in accordance with other findings in Finland (Timonen *et al.* 1995, Remes *et al.* 1996, Remes and Korppi 1996).

The airborne pollutants chosen for examination were $PM_{2.5}$, PM_{10}, reflectance of $PM_{2.5}$ filters, SO_4^{2-} and the elements Fe, Al, Cu, K and Zn. The particles were chosen on the basis of several epidemiological reports that particles have harmful effects on the respiratory health of children and adults (Peters *et al.* 1997, Timonen and Pekkanen 1997, Boezen *et al.* 1998, Delfino *et al.* 1998, Boezen *et al.* 1999, Osynsanya *et al.* 2001, Penttinen *et al.* 2001, Pope *et al.* 2002). SO_4^{2-} and the elements Al, K, Cu and Zn had previously been found to be markers of pollution sources in Raahe (Oravisjärvi *et al.* 2003). It has been reported that iron pollutants in the atmosphere can be deleterious to humans. The inhalation of iron oxide by workers in the metal industries may result in the deposition of iron particles in the lungs (measured values of Fe over 10 mg m^{-3}), producing an X-ray appearance resembling silicosis (Gurzau *et al.* 2003). Exacerbations of respiratory symptoms and respiratory medication use among adults living near a steel factory in Wijk aan Zee, the Netherlands, were found to be associated with both PM_{10} and airborne iron (concentration was 0–6.95 μg m^{-3}) and acute changes in respiratory health were associated with PM_{10} (Dusseldorp *et al.* 1995). The daily iron concentrations in the particulate air pollution at Raahe as measured in winter 1998 varied from 0.024 to 3.4 μg m^{-3} (Oravisjärvi *et al.* 2003).

Air pollution levels in Raahe during the period examined here were generally low, and

Table 3. Adjusted[1)] associations of morning or evening PEF deviations among children with chronic symptoms with 24-hour levels of the elements (Al, K, Cu, Fe, Zn and SO_4^{2-}) in $PM_{2.5}$.

	n	Morning PEF		Evening PEF	
		r	SE	*r*	SE
Al					
Lag 0	93			1.77	7.74
Lag 1	93	–8.42	8.59	–1.39	7.45
Lag 2	92	–3.85	8.62	6.01	7.41
Lag 3	91	12.2	8.5	2.21	7.93
Lag 4	90	–8.71	8.31	–5.24	7.93
D 4	87	–23.5	26.6	0.503	23.7
K					
Lag 0	93			–0.003	0.587
Lag 1	93	–0.339	0.65	–0.046	0.559
Lag 2	92	0.549	0.659	0.427	0.565
Lag 3	91	0.111	0.641	–0.019	0.591
Lag 4	90	–0.301	0.641	–0.202	0.607
D 4	87	0.366	2.04	0.309	1.84
Cu					
Lag 0	93			–104	114
Lag 1	93	–21.2	125	36.1	107
Lag 2	92	–131	127	44.7	110
Lag 3	91	280*	122	–117	116
Lag 4	90	–62.8	125	45.7	119
D 4	87	254	376	25.3	346
Fe					
Lag 0	93			0.154	0.445
Lag 1	93	0.375	0.49	0.052	0.423
Lag 2	92	0.511	0.494	0.522	0.425
Lag 3	91	0.383	0.487	0.134	0.451
Lag 4	90	–0.379	0.483	–0.043	0.458
D 4	87	1.55	1.05	0.597	0.989
Zn					
Lag 0	93			–4.39	3.98
Lag 1	93	3.09	4.48	6.1	3.79
Lag 2	92	5.93	4.45	–0.928	3.86
Lag 3	91	–6.2	4.24	4.77	3.97
Lag 4	90	6.91	4.33	–1.5	4.16
D 4	87	18.5	12.1	15.4	11
SO_4^{2-}					
Lag 0	92			–19.8	21.8
Lag 1	92	–21.7	23.7	2.3	20.9
Lag 2	91	–4.72	24.4	20.1	21.8
Lag 3	90	–20.1	23.6	–12.1	22.1
Lag 4	89	–26.1	23.7	–22.9	22.5
D 4	83	–63	47.8	–9.52	46

[1)] Adjusted for time trend, relative humidity, temperature, influenza epidemic, holidays and autocorrelation. One pollutant was included in the model at a time.
* $p < 0.05$.

Table 4. Results of pulmonary function tests among the children (n = 32) with chronic respiratory symptoms.

	Mean	Min	Max	SD
FVC				
Measured (l)	2.4	1.1	3.7	0.7
Percentage of predicted	85	58	122	16
FEV_1				
Measured (l)	2.0	1.0	3.2	0.6
Percentage of predicted	80	57	104	12

FVC = forced vital capacity, FEV_1 = forced expiratory volume in one second.

the levels did not exceed the accepted values for any of the toxic compounds monitored (Oravisjärvi *et al*. 2003). The study was conducted during the winter, when most particles originate from combustion processes and the temperature mostly remained below 0 °C. There is only one major source of air pollution in the area, namely the steel factory. By contrast, it has been reported that the main air pollution sources in Kuopio, Finland, are soil and street dust and the burning of heavy fuel oil (Hosiokangas *et al*. 1999). The steel factory in Raahe is close to the sea, and when the wind was blowing from that direction towards the air pollution monitoring site, it was bringing with it clean air masses to dilute the emissions. This may be one reason why air pollution levels were low in Raahe (Oravisjärvi *et al*. 2003).

No significant associations were found between PEF and either $PM_{2.5}$, PM_{10} or the reflectance of the $PM_{2.5}$ filters, and there was no clear pattern in the associations between the respiratory symptoms and Fe. No significant associations were found between either respiratory symptoms or PEF and the markers Al, K, SO_4^{2-} and Zn.

The only statistically significant association was observed between morning PEF and Cu (lag 3), but the meaning of this correlation is obscure, because morning or evening PEF had no significant association with the other Cu variables, i.e. lag 1, lag 2, lag 4 or D 4, and in addition the regression coefficient was positive with Cu (lag 3) but negative with the other variables. It is therefore difficult to draw any conclusions from this correlation. There are some reports, however, suggesting that transition metals (salts of iron and copper) are highly oxidative and reactive in biological systems, and that transition metals derived from fuel combustion are present in particulate matter along with ultrafine particles (Donaldson *et al*. 2001). Wilson *et al*. (2002), by studying interactions between ultrafine carbon black particles and transition metals, found that both of these generated oxidants with a chemical potential in a cell-free system, but that the effect of transition metals was diminished in the presence of macrophages because the metals were effectively sequestered by the cells. Transition metals still have little effect on the macrophage cell *in vivo*, but they may have a proinflammatory effect on epithelial cells. The average daily copper concentration in the ambient air of Raahe was low, the concentrations varying from 0.3 to 12.5 ng m^{-3} (Oravisjärvi *et al*. 2003). Exposure to high levels of copper can be harmful, and the breathing of high levels of copper can cause respiratory irritation, including sneezing, thoracic pain, coughing and runny nose. Exposure to inhaled copper is clearly less serious in the general population, however (ATSDR 2004), although the exposure of children to copper is likely to increase in areas where copper concentrations in the air are expected to be high and near lead smelters. Exposures measured in terms of copper concentrations in children's teeth increased with decreasing distance from the smelters (Blanuša *et al*. 1990).

A significant association between PM_{10} and health effects among children with asthmatic symptoms was found in the PEACE panel study in Kuopio, Finland, but not among children with cough only (Nemmar *et al*. 2004). In the present cases the population examined consisted of both children with asthmatic symptoms and children with cough only, with no division made between them, because the number of children included in the series altogether was small ($n = 50$). Raahe is a small town with only about 23 000 inhabitants. The heterogeneity of the symptomatic children could be one reason why there was no association between health effects and air pollution. Asthmatic children have been shown to be more sensitive to the effects of air pollution than non-asthmatic ones or children with only cough (Koenig *et al*. 1993, Roemer *et al*. 1993, Hoek and Brunekreef 1994, Neas *et al*. 1995, Timonen and Pekkanen 1997), but some previous studies have found an effect of particulate pollution on health among non-asthmatic children as well (Pope and Dockery 1992, Hoek and Brunekreef 1994). The present average 24-hour concentrations of PM_{10} were lower than in the above cases, however.

There was an influenza epidemic during the period concerned here, which reduced morning and evening PEF values between 16 February and 15 March 1998. The range of daily PEF values was small most of the time, but high at the time of the influenza epidemic. It is also very likely that the children included in the present series had influenza, because they lived close together and were from the same schools. The time of the influenza epidemic was included in the analyses as a confounder in the linear multivariate first-order autoregressive model, and it is very interesting that the concentrations of $PM_{2.5}$ and PM_{10} were highest at the same time.

In conclusion, a negative association was found here between respiratory health among symptomatic children who lived near a steel factory and particulate air pollution from various sources, but it was not statistically significant. The only statistically significant association was observed between morning PEF and Cu (lag 3), but this is difficult to assess and more investigations would definitely be needed to evaluate its significance.

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