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Fine and coarse particulate air pollution in relation to respiratory health in Sweden

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ABSTRACT Health effects have repeatedly been associated with residential levels of air pollution. However, it is difficult to disentangle effects of long-term exposure to locally generated and long-range transported pollutants, as well as to exhaust emissions and wear particles from road traffic. We aimed to investigate effects of exposure to particulate matter fractions on respiratory health in the Swedish adult population, using an integrated assessment of sources at different geographical scales.

The study was based on a nationwide environmental health survey performed in 2007, including 25 851 adults aged 18–80 years. Individual exposure to particulate matter at residential addresses was estimated by dispersion modelling of regional, urban and local sources. Associations between different size fractions or source categories and respiratory outcomes were analysed using multiple logistic regression, adjusting for individual and contextual confounding.

Exposure to locally generated wear particles showed associations for blocked nose or hay fever, chest tightness or cough, and restricted activity days with odds ratios of 1.5–2 per 10-$\mu g \cdot m^{-3}$ increase. Associations were also seen for locally generated combustion particles, which disappeared following adjustment for exposure to wear particles.

In conclusion, our data indicate that long-term exposure to locally generated road wear particles increases the risk of respiratory symptoms in adults.

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Introduction

There is a large body of epidemiological evidence on health effects of particulate air pollution, including increased respiratory symptoms, decreased lung function and increased hospital admissions and mortality from cardiopulmonary causes [1–5]. Mortality and cardiovascular events have been linked primarily to fine particulate matter ($\leqslant$2.5 μm aerodynamic diameter range ($PM_{2.5}$)), possibly because it can penetrate deep into the lungs and cause systemic inflammation. Coarse particulate matter (commonly defined as particles in the 2.5–10-μm aerodynamic diameter range) has mostly been associated with non-fatal respiratory effects [5]. However, a review by Brunekreef and Forsberg [6] indicated that coarse PM is associated with cardiovascular disease and increased mortality as well. It is difficult to separate health effects of long-term exposure to exhaust emissions and wear particles from road traffic, and to separate effects of locally generated and long-range transported pollutants. Further epidemiological evidence to disentangle these relationships is needed. Although the background concentration of particulate air pollution in the Nordic countries is lower than in the rest of Europe [7], there are major concerns about the health effects of exposure to particulate air pollution from traffic [8–10]. The use of studded winter tyres on cars and the gritting of roads are common in northern Europe, and road wear constitutes an important source of coarse PM [11]. There are only a few large population studies investigating the health effects of air pollution from road traffic, which include urban as well as non-urban adult populations, and use spatially resolved air pollution data. Within the ROADSIDE project, we have data on air pollution exposure and health outcomes for ~26 000 people aged 18–80 years over the whole country of Sweden. The main objectives of the present study were to investigate associations between exposure to total PM_{10}, long-range transport particles, locally generated combustion particles and locally generated road wear particles at the subject's home address, and self-reported respiratory health outcomes in a general population sample in Sweden.

Methods

Study population and design

ROADSIDE is a large cross-sectional study based on the National Environmental Health Survey (NEHS 2007) conducted in Sweden in 2007 [12]. The aim of this nationwide postal survey was to study exposure to several environmental and lifestyle factors, as well as related health outcomes, in the adult population (18–80 years of age) who had lived in Sweden for $\geqslant$5 years. According to the Swedish population register, this target population consisted of 6 761 887 persons. Random sample selection was conducted in two steps. First, a sample of 10 500 persons, equally distributed over Sweden's 21 counties were selected. Secondly, this sample was enhanced with 33 405 persons from 10 counties due to supplementary funding. In total, the survey was sent to 43 905 persons (0.6% of the target population) of whom 25 851 (59.4%) responded. The survey was sent out and processed by Statistics Sweden (Stockholm, Sweden) and had been approved by the regional ethical committee in Stockholm [12]. A map of Sweden with its county borders, showing response rates and counties with enhanced sampling, is provided in figure 1a.

Exposure assessment

Individual exposure to PM was assessed as average outdoor levels at the subject's home address, estimated by dispersion modelling. The home addresses of the respondents to the NEHS 2007 were geocoded by the Swedish Mapping, Cadastre and Land Registration Authority (Gävle, Sweden). The SIMAIR modelling system [13, 14] was used to estimate address-specific outdoor levels of PM_{10}. SIMAIR is a national modelling system that combines air pollution contributions on three scales: a regional contribution from simulation on the European scale; an urban contribution calculated on a 1×1-km grid over ~100 cities and towns in Sweden; and a local contribution from traffic within a radius of 250 m from the home address. The determination of the local traffic impact is based on a unique national road and traffic database, covering the majority of Swedish roads, managed by the Swedish Transport Administration (Borlänge, Sweden) [15]. Emission factors for the exhaust part of PM_{10} are calculated by the Assessment and Reliability of Transport Emission Models and Inventory Systems (ARTEMIS) working group [16]. A semi-empirical model is used for the non-exhaust part of PM_{10}, considering generation, suspension and resuspension of wear particles in the supermicron fraction [17]. The SIMAIR system enables splitting of the PM_{10} size fractions for the urban as well as, the local traffic contribution of PM_{10}. Exhaust- and combustion-related particles were assumed to have a diameter <1 μm (indicated as PM_1) and the resuspended road and tyre wear particles were assumed to have a diameter ranging from 1 to 10 μm (indicated as PM_{1-10}). The long-range regional contribution to PM_{10} was estimated to be equally distributed between the supermicron (PM_{1-10}) and submicron (PM_1) fraction, based on observations from a rural background monitor in central Sweden [18]. The origin and composition of these two fractions in the regional contribution is different from the local traffic and urban contribution. The regional PM_1 concentration contains a larger proportion of aged inorganic and organic secondary aerosols, and to a lesser extent sea salt, while the regional PM_{1-10} concentration mainly contains

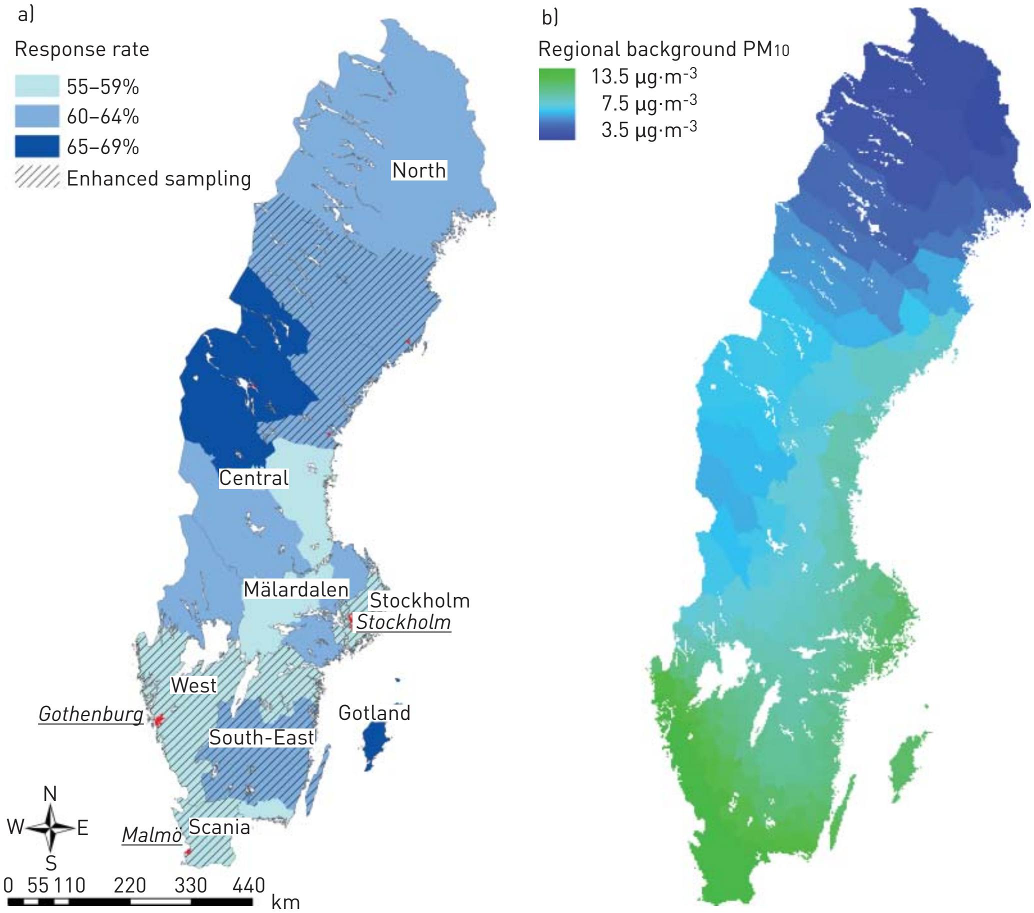

FIGURE 1 a) Map of Sweden showing study regions and main cities (underlined), response rates, and areas in which enhanced participant sampling in the Swedish Environmental Survey of 2007 took place. b) Map of Sweden showing modelled regional background particulate matter <10 µm aerodynamic diameter range (PM_{10}) (long-range transport) particle concentration.

sea salt and mineral dust transported over larger distances. The SIMAIR system uses meteorological input data relevant for dispersion models, such as wind speed and direction, temperature, cloudiness, global radiation, sensible heat flux, friction velocity, humidity and precipitation. Further details of the SIMAIR modelling system, as well as results of the model validation, have been described previously [13, 14].

In this study, we investigated associations for: total PM_{10} level, long-range transport particles (regional PM_{10} contribution), locally generated PM_{10} level (local traffic and urban PM_{10} contribution), locally generated combustion particles (local traffic and urban PM_1 fraction) and locally generated wear particles (local traffic and urban PM_{1-10} fraction).

Health outcome assessment

The NEHS 2007 survey enquired about annoyance from specific sources, prevalence of respiratory, cardiovascular and allergic symptoms and diseases, and quality of life. Furthermore, it contained questions about smoking and sunbathing behaviour, home and living environment characteristics, food and water consumption, and mobile phone use. Respondents returned the questionnaire to Statistics Sweden. Statistics Sweden digitised the answers, added registry data on country of origin, civil status, income, education and home geographical coordinates, and estimated a survey calibration weight variable. This calibration weight variable was used to calculate results that are representative for the target population. Within a geographical sampling stratum, the differences in calibration weight represent differences in response rate in substrata, defined by sex, age, civil status, income, education and country of origin. The mean weight was 260 and ranged from six to 1874.

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Because of the cross-sectional nature of the survey and the self-reporting, we focused on current and recent respiratory health in the present study. Respiratory health outcomes analysed were: asthma symptoms in the past 12 months, the use of asthma medication in the past 12 months, having a blocked nose or hay fever symptoms for >4 days a week in the past 12 months, being woken by chest tightness or cough in the past 3 months, and having restricted activity days due to respiratory symptoms in the past 3 months.

Statistical analyses

Descriptive statistics were produced for the total study population and stratified by region. The regions were defined as follows: Scania (Skåne county); South East (Östergötland, Jönköping, Kronoberg, Kalmar and Blekinge counties, and the island of Gotland); Mälardalen (Uppsala, Södermanland, Örebro and Västmanland counties); West (Värmland, Västra Götaland and Halland counties); Stockholm (Stockholm county); Central (Jämtland, Västernorrland, Gävleborg, Dalarna counties); and North (Norrbotten and Västerbotten counties) (fig. 1a).

Associations between traffic-related PM_{10} exposure and respiratory health outcomes were analysed using multivariate logistic regression adjusted for the respondent's sex, age, educational level, household income, smoking, passive smoking, moisture damage or mould exposure in the home, and country of birth (table 1). Furthermore, we used the proportion of higher educated adults and the proportion of unemployed adults in the municipality to additionally adjust for contextual confounding. The data to construct the two contextual variables were derived from the internet databases of Statistics Sweden for level of education in municipalities in 2007 [19], and the Municipality Database (Kommundatabasen) for unemployment rate in 2007 [20]. For total PM_{10}, long-range transport particles, locally generated PM_{10} and locally generated wear particles, associations were calculated per 10-$\mu g \cdot m^{-3}$ increase, while for the locally generated combustion particles, associations were calculated per 1-$\mu g \cdot m^{-3}$ increase. To compare the health impact of locally generated combustion particles *versus* locally generated wear particles, we also calculated associations by an increase from the fifth to the 95th percentile in exposure levels.

In order to explore whether differences in response rate in socioeconomic substrata were related to levels of air pollution, and thus potential confounders, we calculated the correlations between the relative calibration weights and total PM_{10} exposure.

Results

Female and middle-aged respondents were slightly over-represented in the study population, with little regional variation (table 1). The largest proportion of persons with higher vocational or university education was in the Stockholm region. Smokers constituted 18% of the total study population, with a lower proportion in the North region (14%). Passive smoking was most common in the southern region Scania. Moisture damage was present in ~15% of the homes, while visible mould was reported for 5%. More than 90% of the study population was of Nordic origin. The highest proportions of participants of non-Nordic origin were in Scania and Stockholm.

The estimated residential outdoor levels of particulate air pollution in Sweden could be modelled for 25 846 of the 25 851 study participants (table 2 and figs 1b and 2). Total PM_{10} levels for our total study population appeared to have a Gaussian distribution with a mean of 11.3 $\mu g \cdot m^{-3}$, a 5–95% range from 8.0 to 16.1 $\mu g \cdot m^{-3}$, and a few addresses between 20 and 40 $\mu g \cdot m^{-3}$. Highest mean concentrations of total PM_{10} were seen in the regions Scania, Stockholm and the West, which contain the three largest cities in Sweden: Stockholm, Gothenburg (region West) and Malmö (region Scania). In all regions, the total PM_{10} level was dominated by long-range transport particles, with an overall average of 10 $\mu g \cdot m^{-3}$ (88% of the total PM_{10} level). Long-range transport particle levels (regional PM_{10} contribution) ranged from ~4 $\mu g \cdot m^{-3}$ (region North) to 14 $\mu g \cdot m^{-3}$ (region Scania) (fig. 1b). Locally generated PM_{10} level had a skewed distribution with an average of 1.3 $\mu g \cdot m^{-3}$. Overall, the locally generated PM_{10} level was dominated by wear particles (62%) with an average of 0.8 $\mu g \cdot m^{-3}$, the rest being traffic exhaust and other combustion particles with an average of 0.5 $\mu g \cdot m^{-3}$. The highest levels of locally generated combustion particles were found in the regions Stockholm, Mälardalen, and the South East and Gotland. The highest levels of locally generated road wear particles were found in the regions Stockholm, Mälardalen and West. The differences in response rate across geographic and socioeconomic substrata of the population were not related to estimated total PM_{10} levels (data not shown).

The prevalence of respiratory outcomes is shown in table 3. Asthma symptoms and the use of asthma medication in the past 12 months seemed to be very similarly reported, by about 8% of the total study population. There were distinct regional differences, with the highest prevalence in the Mälardalen region

TABLE 1 Characteristics of the total study population included in the Swedish Environmental Survey of 2007, and stratified by region

Characteristic	Total	Scania	South East and Gotland	Mälardalen	West	Stockholm	Central	North
Total population n	25 851	1122	10 305	1182	3941	5921	2147	1233
Sex								
Male	11 832 (45.8)	496 (44.2)	4724 (45.8)	558 (47.2)	1829 (46.4)	2632 (44.5)	1016 (47.3)	577 (46.8)
Female	14 019 (54.4)	626 (55.8)	5581 (54.2)	624 (52.8)	2112 (53.6)	3289 (55.6)	1131 (52.7)	656 (53.2)
Age years								
18–29	3513 (13.6)	167 (14.9)	1361 (13.2)	167 (14.1)	567 (14.4)	781 (13.2)	256 (11.9)	214 (17.4)
30–39	3900 (15.1)	187 (16.7)	1360 (13.2)	190 (16.1)	646 (16.4)	1066 (18.0)	284 (13.2)	167 (13.5)
40–49	4661 (18.0)	202 (18.0)	1824 (17.7)	194 (16.4)	670 (17.0)	1199 (20.3)	380 (17.7)	192 (15.6)
50–59	4852 (18.8)	198 (17.7)	1946 (18.9)	229 (19.4)	754 (19.1)	1045 (17.7)	441 (20.5)	239 (19.4)
60–69	5207 (20.1)	210 (18.7)	2228 (21.6)	249 (21.1)	722 (18.3)	1127 (19.0)	437 (20.4)	234 (19.0)
70–80	3718 (14.4)	158 (14.1)	1586 (15.4)	153 (12.9)	582 (14.8)	703 (11.9)	349 (16.3)	187 (15.2)
Educational level								
Primary school	4659 (18.0)	193 (17.2)	2131 (20.7)	219 (18.5)	721 (18.3)	779 (13.2)	434 (20.2)	182 (14.8)
High school	11 030 (42.7)	432 (38.5)	4528 (43.9)	486 (41.1)	1631 (41.4)	2415 (40.8)	986 (45.9)	552 (44.8)
Lower vocational education	1489 (5.8)	75 (6.7)	504 (4.9)	77 (6.5)	254 (6.5)	399 (6.7)	114 (5.3)	66 (5.4)
Higher vocational education or university	6921 (26.8)	325 (29.0)	2417 (23.5)	318 (26.9)	1057 (26.8)	2003 (33.8)	457 (21.3)	344 (27.9)
Smoking								
Nonsmoker	12 800 (49.5)	544 (48.5)	5152 (50.0)	591 (50.0)	1954 (49.6)	2828 (47.8)	1077 (50.2)	654 (53.0)
Ex-smoker	8182 (31.7)	355 (31.6)	3190 (31.0)	372 (31.5)	1195 (30.3)	1996 (33.7)	688 (32.0)	368 (31.3)
Current smoker	4559 (17.6)	211 (18.8)	1836 (17.8)	196 (16.6)	741 (18.8)	1039 (17.6)	359 (16.7)	177 (14.4)
ETS exposure in home	1865 (7.2)	98 (8.7)	749 (7.3)	80 (6.8)	290 (7.4)	435 (7.4)	133 (6.2)	80 (6.5)
Moisture damage in home	3971 (15.4)	159 (14.2)	1518 (14.7)	199 (16.8)	663 (16.8)	891 (15.1)	379 (17.7)	162 (13.1)
Visible mould in home	1368 (5.3)	66 (5.9)	486 (4.7)	67 (5.7)	250 (6.3)	352 (5.9)	88 (4.1)	59 (4.8)
Country of birth								
Nordic country	23 921 (92.5)	993 (88.5)	9642 (93.6)	1099 (93.0)	3616 (91.8)	5282 (89.2)	2096 (97.6)	1193 (96.8)
Europe/North America	1110 (4.3)	79 (7.0)	422 (4.1)	41 (3.5)	196 (5.0)	330 (5.6)	29 (1.4)	13 (1.1)
Other	820 (3.2)	50 (4.5)	241 (2.3)	42 (3.6)	129 (3.3)	309 (5.2)	22 (1.0)	27 (2.2)
Higher-educated adults in municipality %[#, ¶]	16.8±6.9	18.5±7.9	14.3±5.6	15.9±7.1	17.4±5.7	21.8±7.5	13.1±3.3	17.5±7.2
Unemployed adults in municipality %[¶]	11.5±3.9	12.2±2.7	12.8±3.2	12.1±3.0	11.7±2.5	7.3±3.2	14.2±3.3	13.0±3.6

Data are presented as n (%) or mean±SD, unless otherwise stated. ETS: environmental tobacco smoke. #: higher vocational education or university; ¶: contextual variable on municipality level.

and lowest in Scania and West. Blocked nose or hay fever for >4 days a week in the past 12 months was reported by 18.0%, with smaller regional differences. Being woken by chest tightness or cough in the past 3 months was reported by 19.4% and restricted activity days due to respiratory symptoms in the past 3 months by 10.9% of the population, both also with smaller regional differences.

Figure 3 shows associations between total PM_{10}, as well as the different PM fractions, and respiratory health outcomes in the total study population. Total PM_{10} concentration was positively associated with chest tightness or cough and restricted activity days in the past 3 months. The long-range transport part of PM_{10} was not associated with any outcome except for a non-expected marginally significant inverse association with asthma symptoms (OR per 10-$\mu g \cdot m^{-3}$ difference 0.69, 95% CI 0.49–0.99). Locally generated PM_{10} was significantly associated with being woken by chest tightness or cough in the past 3 months and with restricted activity days in the past 3 months, but also with blocked nose or hay fever in the past 12 months.

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TABLE 2 Estimated residential outdoor levels of total particulate matter <10 μm aerodynamic diameter range (PM_{10}) and different PM fractions for the total study population in the Swedish Environmental Survey in 2007, and stratified by region

Exposure	Total	Scania	South East and Gotland	Mälardalen	West	Stockholm	Central	North
Subjects n	25 846	1122	10 305	1182	3939	5921	2147	1230
PM_{10} total μg·m^{-3}								
Mean ± SD	11.3 ± 2.5	13.7 ± 1.2	10.5 ± 0.9	10.0 ± 1.1	12.8 ± 2.5	13.2 ± 2.6	9.0 ± 1.3	7.4 ± 1.6
Median (IQR)	10.8 (2.8)	13.4 (1.4)	10.5 (1.3)	9.9 (1.6)	12.8 (3.5)	12.8 (3.7)	8.8 (1.7)	7.5 (2.2)
Range	3.6–40.0	11.1–17.6	8.8–14.7	8.1–15.8	6.5–21.4	9.7–40.0	6.1–14.2	3.6–11.3
Long-range transport particles μg·m^{-3}								
Mean ± SD	10.0 ± 1.5	13.0 ± 0.5	9.8 ± 0.7	9.1 ± 0.5	11.6 ± 1.4	10.2 ± 0.2	8.2 ± 0.7	6.8 ± 1.3
Median (IQR)	10.0 (1.4)	13.2 (0.4)	9.7 (1.2)	9.0 (0.9)	12.3 (1.9)	10.2 (0.2)	8.4 (1.1)	6.6 (2.5)
Range	3.6–13.6	11.0–13.6	8.8–12.0	8.1–10.2	6.5–13.3	9.7–10.7	6.1–9.3	3.6–8.6
Locally generated PM_{10} μg·m^{-3}								
Mean ± SD	1.3 ± 1.8	0.6 ± 0.8	0.7 ± 0.7	0.9 ± 1.0	1.3 ± 1.6	3.0 ± 2.6	0.8 ± 0.9	0.6 ± 0.7
Median (IQR)	0.7 (1.9)	0.2 (1.0)	0.5 (1.1)	0.7 (1.6)	0.5 (2.3)	2.5 (3.5)	0.3 (1.3)	0.4 (1.0)
Range	0–29.8	0–4.2	0–5.2	0–6.9	0–8.8	0–29.8	0–5.5	0–3.8
Locally generated wear particles μg·m^{-3}								
Mean ± SD	0.8 ± 1.3	0.4 ± 0.6	0.4 ± 0.5	0.5 ± 0.7	0.8 ± 1.1	2.0 ± 2.0	0.4 ± 0.5	0.3 ± 0.4
Median (IQR)	0.3 (1.1)	0.1 (0.6)	0.2 (0.5)	0.3 (0.9)	0.3 (1.4)	1.5 (2.3)	0.1 (0.5)	0.2 (0.5)
Range	0–25.2	0–2.9	0–4.3	0–5.4	0–7.0	0–24.2	0–3.8	0–2.8
Locally generated combustion particles μg·m^{-3}								
Mean ± SD	0.5 ± 0.6	0.2 ± 0.3	0.3 ± 0.4	0.4 ± 0.4	0.4 ± 0.5	1.0 ± 0.8	0.4 ± 0.5	0.3 ± 0.4
Median (IQR)	0.3 (0.8)	0.1 (0.4)	0.2 (0.6)	0.3 (0.7)	0.1 (0.8)	1.1 (1.3)	0.1 (0.7)	0.2 (0.5)
Range	0–5.6	0–1.5	0–1.9	0–1.5	0–3.0	0–5.6	0–2.9	0–3.5

IQR: interquartile range.

When separating the locally generated particles into wear and combustion particles, both fractions showed elevated risks for respiratory symptoms. Locally generated wear particles were significantly associated with blocked nose or hay fever (OR per 10-μg·m^{-3} difference 1.40, 95% CI 1.02–1.90), chest tightness or cough (OR 1.91, 95% CI 1.40–2.60) and restricted activity days (OR 1.50, 95% CI 1.05–2.16), while locally generated combustion particles were significantly associated with blocked nose or hay fever (OR per 1-μg·m^{-3} difference 1.09, 1.02–1.16) and being with woken by chest tightness or cough (OR 1.08, 95% CI 1.01–1.15).

In order to compare the effects of locally generated wear and combustion particles we also calculated associations for an exposure difference between the fifth and 95th percentile of the distribution in the study participants. These exposure differences were 3.22 and 1.74 μg·m^{-3}, respectively. The corresponding odds ratios were fairly similar: blocked nose or hay fever 1.11 (95% CI 1.00–1.23) and 1.15 (1.03–1.29), chest tightness or cough 1.23 (1.11–1.36) and 1.14 (1.02–1.28), and restricted activity days 1.14 (1.01–1.28) and 1.10 (0.97–1.27), respectively.

Exposure to locally generated wear and combustion particles were highly correlated ($r=0.75$) and in regression models including both exposure parameters, the effect of the combustion particles disappeared while the effect of the wear particles was strengthened (data not shown).

When we performed analyses restricting the population to those resident at the current address for $\geqslant 5$ years, the results were essentially the same.

Discussion

We have investigated the associations between exposure to different fractions of particulate air pollution and current or recent respiratory symptoms in Swedish adults. Our results indicate significant effects of exposure to total PM_{10} and locally generated PM_{10}, including wear and combustion particles,

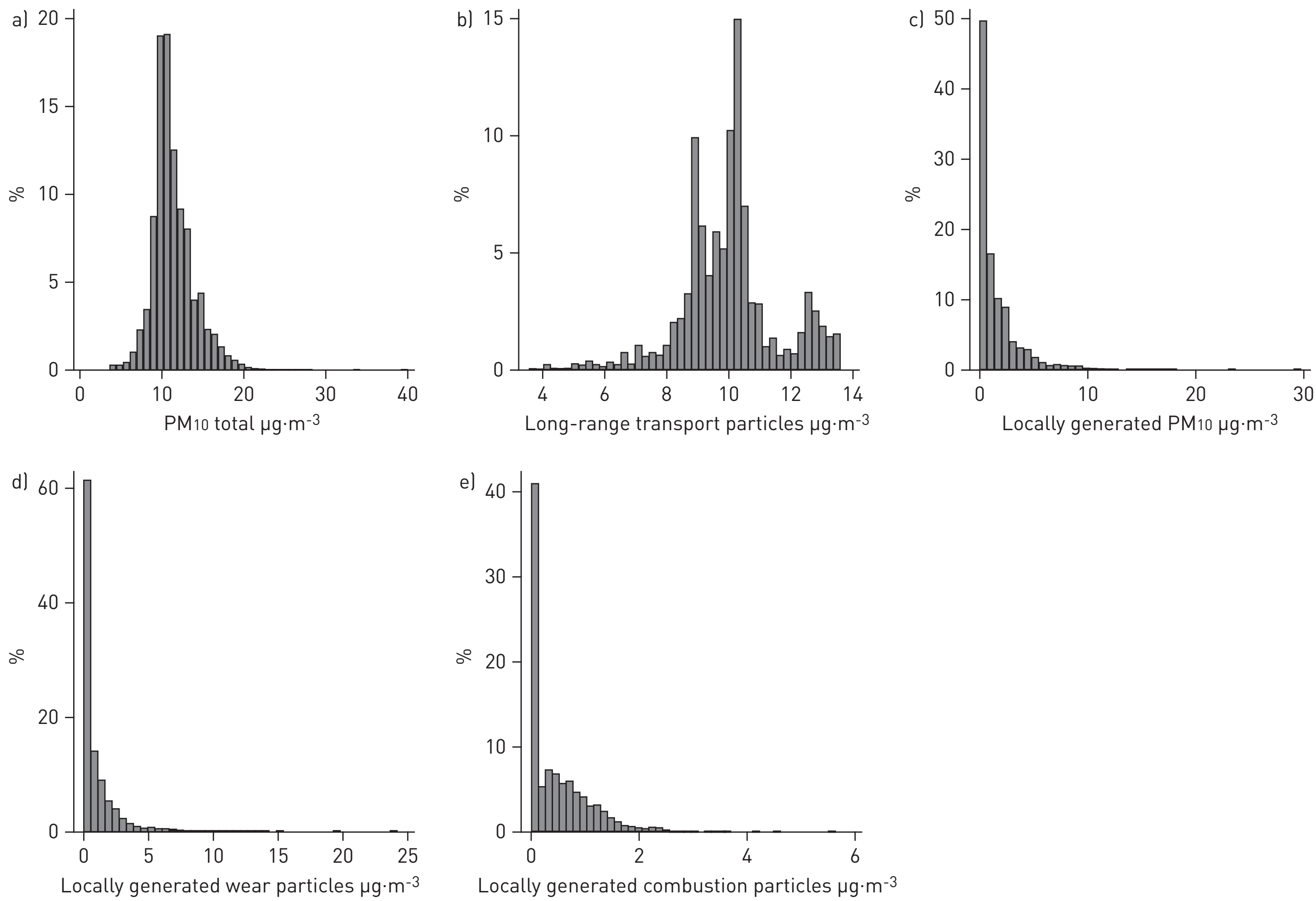

FIGURE 2 Distribution of modelled outdoor levels of total particulate matter <10 µm aerodynamic diameter range (PM_{10}) and of different particle fractions at the home addresses of the study population in the Swedish Environmental Survey of 2007. Data are presented as % of addresses sampled in the survey. a) Total PM_{10}, b) long-range transport particles, c) locally generated PM_{10}, d) locally generated wear particles and e) locally generated combustion particles.

on the prevalence of restricted activity days due to respiratory symptoms, being woken by chest tightness or cough, and blocked nose or hay fever (only statistically significant for locally generated PM_{10}). However, we did not find any consistent effects of PM exposure on asthma outcomes in the present study.

Our results are broadly in line with other studies showing respiratory effects from coarse particles. A systematic review of the effects of coarse airborne particles on health observed that in studies of chronic obstructive pulmonary disease (COPD), asthma and respiratory admissions, coarse PM has a stronger or equally strong short-term effect as fine PM, suggesting that coarse PM may lead to adverse responses in the lungs triggering processes leading to hospital admissions [6]. Among recent studies, CHEN *et al.* [21] showed that ambient coarse PM was positively associated with respiratory hospital admissions among the elderly population in Vancouver, Canada. LIN *et al.* [22] found a detrimental effect of coarse particulate matter on hospitalisation for respiratory infections in children. A study conducted in France also showed positive associations between exposure to $PM_{2.5–10}$ and hospitalisation for respiratory infections in children [23]. Another French study, using a dispersion model, found positive associations between PM_{10} exposure and asthma and allergies in children [24].

It was possible to explore the effects of different particle size fractions, which would have been more problematic in smaller areas because of the locally very high correlation between the fractions. In our study, locally generated wear particles appear less harmful than combustion particles on a mass basis, but when the associations were calculated for difference between the fifth and 95th percentile of the distribution of the two fractions the results were rather similar. When both these types of locally generated particles were entered into the same model, the effect of the combustion particles disappeared while the effect of the wear particles was strengthened. However, it should be noted that in our study

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TABLE 3 Prevalence of self-reported recent respiratory symptoms in the total study population in the Swedish Environmental Survey of 2007, and stratified by region

Outcome	Total	Scania	South East and Gotland	Mälardalen	West	Stockholm	Central	North
Subjects n	25 851	1122	10 305	1182	3941	5921	2147	1233
Asthma symptoms past 12 months	7.5	6.0	7.1	10.2	6.6	8.2	7.6	8.3
Asthma medication use past 12 months	7.8	7.6	7.5	10.1	6.9	8.4	7.6	8.7
Blocked nose/hay fever >4 days a week past 12 months	18.0	19.1	17.4	18.3	16.9	20.3	16.3	17.3
Woken by chest tightness/ cough past 3 months	19.4	19.1	19.2	22.4	19.2	20.1	18.6	17.8
Restricted activity days due to respiratory symptoms past 3 months	10.9	10.3	10.2	10.7	11.6	12.4	10.1	9.2

Data are presented as %, unless otherwise stated.

the two fractions, to a large extent, come from the same source, and thus are substantially correlated ($r=0.75$), which implies that the results regarding the specific role of each fraction have to be interpreted with caution.

Our study was based on a large sample (nearly 26 000 people) distributed over a large geographical area (449 964 km^2), including densely populated areas, the three major cities Stockholm, Gothenburg and Malmö, as well as rural areas all over Sweden. This resulted in a greater than usual exposure contrast for a Swedish population and in a high statistical power for the analyses.

The response rate of the initial environmental health survey was reasonable (59.4%). From a non-response analysis of the question "How do you assess your general health status, compared to others of your age?", it was concluded that the study population well represented the target population of long-term Swedish residents aged 18–80 years [12]. The difference in response rates over the socioeconomical and geographical strata was not related to air pollution exposure, which implies that no bias was introduced by the lack of total participation in the survey.

A limitation of this study was the cross-sectional study design, which makes it difficult to study effects of long-term exposure. Subjects who have developed respiratory problems may have moved away from areas with high air pollution exposure, which could result in apparent protective effects from air pollution. We therefore focussed on the effects of air pollution exposure on current and recent respiratory symptoms (in the past 3 months or in the past year). Restricting the analyses to subjects living at their address for >5 years did not substantially change the results.

The different air quality gradients, as simulated by the SIMAIR model system, vary in quality. The gradient of the regional contribution over Sweden was estimated from a combination of model results and measurement data, and is expected to have high validity for the model year (2004). The validity of the urban contribution of PM is highly dependent on the information on traffic in the 1×1-km grid, which was of good quality [13, 14]. The total contribution from residential wood combustion to PM exposure, as well as its spatio-temporal distribution, is less well known. As for the local impact of traffic emissions within a radius of 250 m, the spatial distribution of the emissions should be well described for all state-owned roads and for the major city roads. However, traffic on minor city roads was to a great extent simulated, and thus described with poorer quality. The modelling was performed with hourly input of meteorology for the model year 2004. The questionnaire data are from 2007 but very little is expected to have happened to any of the gradients in the years before and after the model year.

The SIMAIR model output has been extensively evaluated against monitor data from 12 urban background and 15 street site locations [25]. The results of these evaluations show that the SIMAIR model performs substantially better than the European Union Directive's quality criteria for PM_{10}, that require a maximum deviation between the simulated and monitored annual average concentration levels of <50% for 90% of individual monitoring points [26]. Furthermore, the results of the comparison of the SIMAIR model with

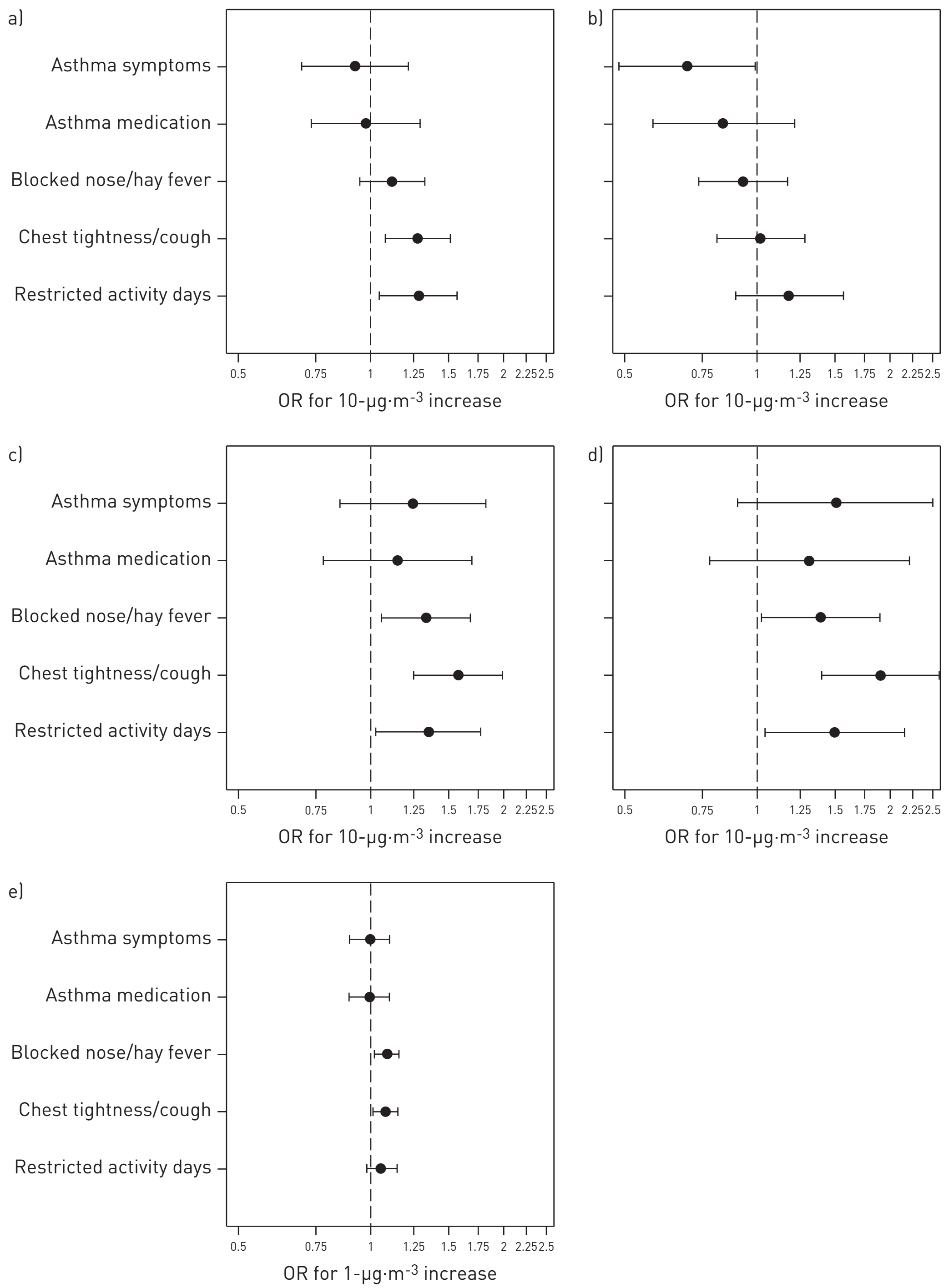

FIGURE 3 Adjusted associations between different particulate matter (PM) fractions and self-reported current respiratory health outcomes in the Swedish Environmental Survey of 2007. One-pollutant models adjusted for the individual confounders sex, age, educational level, smoking, passive smoking, mould and moisture exposure in the home and country of birth, and the contextual confounders proportion of highly educated and unemployed people in the municipality. a) Total particulate matter <10 µm aerodynamic diameter range (PM_{10}), b) long-range transport particles, c) locally generated PM_{10}, d) locally generated wear particles and e) locally generated combustion particles. Data are presented as odds ratios and error bars represent 95% confidence intervals.

monitored data at six urban background and four street site locations in different parts of Sweden showed that the difference between simulated and monitored annual averages of PM_{10} levels were below ~20% for urban background and ~10% for street level concentrations, with correlation coefficients for the time-series of daily average PM_{10} varying between 0.56 and 0.76.

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An important uncertainty may be found in basing the exposure determination on outdoor levels at the home address only. People spend most of their time indoors, but indoor PM levels in Sweden are similar to outdoor levels [27], and the home address is a common approach found to constitute a fairly good proxy, especially for $PM_{2.5}$ exposure [28]. However, other environments that may give significant contributions are school, the workplace and traffic. Future studies could benefit from including estimates of these contributions to individual exposure.

Health outcome variables used in this study were self-reported and derived from a questionnaire containing questions on both living environment and personal health. Self-reporting of health is clearly subject to error [29]. Biased reporting of the outcomes associated with the estimated air pollution is, however, unlikely as the data on air pollution levels used in our analyses were derived independently from the questionnaire. Our study has been conducted in a very heterogeneous study area varying from very sparsely populated rural areas to the urban areas of Stockholm, Gothenburg and Malmö. Furthermore, the exposure to air pollution and the prevalence of the investigated respiratory symptoms vary over the country as well. Earlier studies in Sweden have found that the socioeconomic context of the area of residence is associated with levels of air pollution [30] and disease risk [31]. Potential contextual confounding by the socioeconomic position of the area of residence has been taken into account by conducting multilevel analyses, adjusting for the percentage of highly educated persons and of unemployed people in the municipality. These two contextual variables were both associated with air pollution levels and the investigated respiratory symptoms, and including them in the models slightly attenuated the risk estimates.

The apparent protective effect of long-range transport particles on asthma outcomes is probably due to the fact that asthma is more prevalent in the north, while long-range transport particle concentration shows the opposite gradient. Earlier studies in Sweden have also shown an increased prevalence of asthma and COPD in adults and children in northern Sweden compared with southern Sweden [32–35]. Climate factors such as temperature and humidity, and lifestyle factors such as nutrition or indoor air quality may explain these differences in prevalence. However, the exact reason is still unknown, underlining the need for great caution in the interpretation of studies with large-scale differences in both environmental contaminants and health effects. In conclusion, our data indicate that exposure to locally generated road wear particles increases the risk of respiratory symptoms in adults.

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