Are day-to-day variations of airborne particles associated with emergency ambulance dispatches?

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Background: Much of the evidence on the health effects of airborne particles is based on mortality and hospital admissions, while the evidence from other morbidity indicators is still limited.
Objective: To measure the relationship between particles with diameter below 10 μm (PM_{10}) and emergency ambulance dispatches (EAD).
Methods: Daily EAD for six towns of the Emilia-Romagna region (Italy) were obtained from a database collecting real-time data. Time series analyses were performed, and city-specific estimates were combined using meta-analytic techniques.
Results: We found a significant percentage change of EAD associated with a 10 μg/m^3 increase of PM_{10} for non-traumatic diseases (0.86%, 95%CI: 0.61,1.1%). A positive relationship was also found for cardiovascular and respiratory diseases without reaching statistical significance. The risks were much higher in the warm (April–September) than in the cold season (January–March and October–December).
Conclusions: Emergency ambulance dispatches provide useful insight into the health effects of air pollution and may be useful to establish surveillance systems.

Keywords: Air pollution, Airborne particles, PM_{10}, Emergency ambulance dispatches, Time series

Introduction

There is convincing evidence that short-term exposure to airborne particles is associated with adverse health effects.[1–4] Much of this evidence is based on mortality and hospital admission data. Additional evidence comes from studies based on data generally not present in administrative health databases, such as asthma attacks,[5] doctor house calls,[6] daily clinic visits,[7] general practitioner consultations,[8] and telephone calls.[9] However, the evidence from these studies is still limited, inconsistent, and less than robust.

To our knowledge, no studies have analyzed the use of emergency ambulance dispatches (EAD) as an indicator of the health effects of particulate matter. In this report, we present the results of the analysis of the association between concentrations of ambient particulate matter with aerodynamic diameter<10 μm (PM_{10}) and EAD in Emilia-Romagna, a highly polluted region in northern Italy.

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Methods

The region of Emilia-Romagna is located in Northern Italy and has approximately 4.3 million inhabitants. All the main urban areas are located in the plain, which comprises nearly half of the regional territory. The area is characterized by a sub-continental climate with cold winters and hot summers (typical monthly mean temperatures ranging from 1 to 26°C), high humidity levels (typical monthly mean relative humidity ranging from 60 to 84%), and low wind intensities (typical annual mean wind intensities of about 2 m/s).

The emergency ambulance service covers the entire region, and EAD data are routinely stored in real time in a database maintained by the Regional Health Authority. The database contains information on all ambulance dispatches in response to persons who have called the emergency service number (118), collected via a standardized telephone interview carried out by specially trained operators with the same criteria and procedures across the region. Each record in the ambulance dispatch database includes fields including date, hour, and location of the call, as well as information regarding the person requiring assistance, including sex, age, critical urgency (assigned before ambulance dispatch), and disease as

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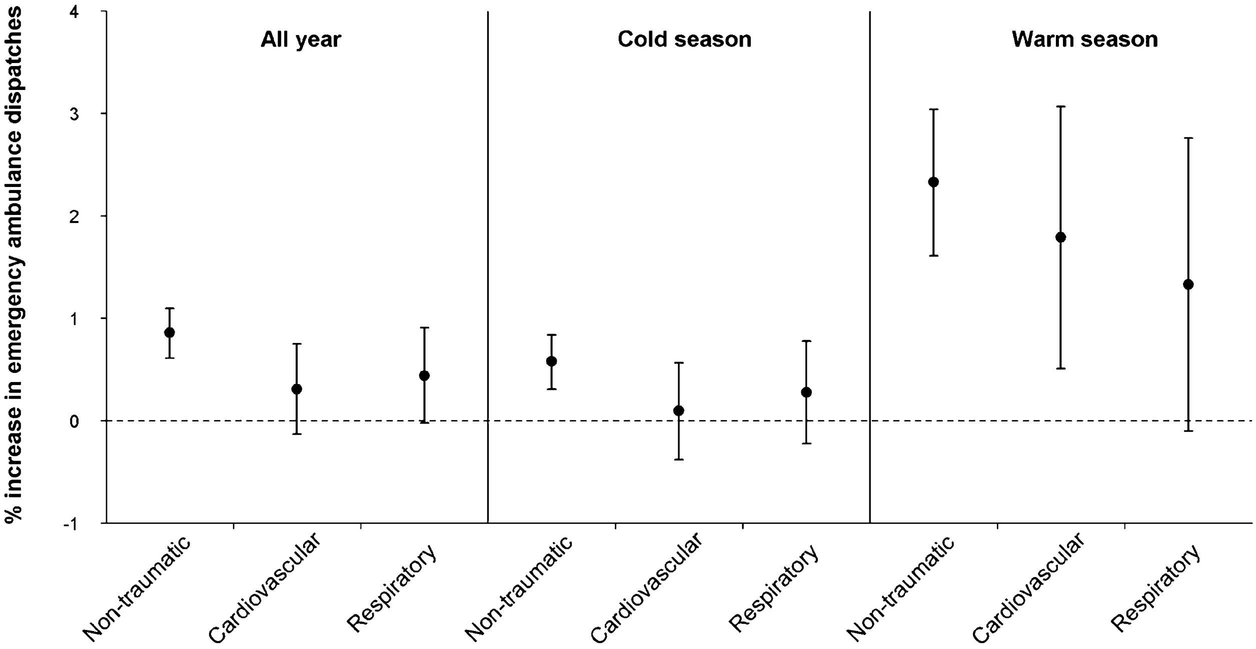

Figure 1 All year and season-specific meta-analytic estimates of percent increase in emergency ambulance dispatches (EAD) for non-traumatic, cardiovascular, and respiratory diseases for a 10 μg/m^3 increase in PM_{10}.

coded among 10 broad groups (alcoholic, traumatic, cardiovascular, respiratory, neurological, psychiatric, neoplastic, intoxication (poisoning), other diseases, and unidentified diseases). In this study, the analyses were conducted for cardiovascular, respiratory, as well as all non-traumatic diseases (i.e. all diseases except the traumatic ones). Traumatic diseases were used as a control variable because no known relation with particle concentrations was expected. Emergency ambulance dispatches data were collected from the database for people aged 35+ for the period from 2002 to 2006 for 6 out of 10 of the chief towns of the Emilia-Romagna region (Bologna, Modena, Parma, Reggio, Ferrara, and Piacenza – see Fig. 1). The total population of the cities in the study area was about 1.1 million, with 68.6% aged 35 or older. The four cities located along the coast of the Adriatic Sea (Rimini, Ravenna, Forlì, and Cesena) were excluded from the study because of (1) short-term population dynamics driven by summer tourism that heavily affects emergency ambulance temporal patterns and (2) different compositions of particulate matter due to sea breeze effect.

Owing to the fact that almost all air pollution monitoring stations in the region are located within urban areas, only ambulance interventions within the cities were included in the analysis to avoid misclassification of subjects' exposure.

Meteorological and environmental data were provided by the monitoring networks of the Regional Agency for Environmental Protection in Emilia-Romagna. Daily average concentrations of PM_{10} were collected from the ISO 9001-certified fixed site monitoring network located within the selected urban areas. With respect to PM_{10}, we considered only those stations where particulate concentrations were measured by means of beta absorption or gravimetric methods, which have been shown to be well in agreement.[10] For the analysis, we included only stations with more than 75% of data complete. Missing data were filled by means of procedures based on the hypothesis of fixed ratios between the data collected in each station and the average of the data collected in the other monitoring sites within the same city. When daily data were missing for all the stations, the values were treated as missing. According to the findings of a previous analyses on mortality data,[11] exposure to PM_{10} was calculated by averaging the monitoring station data over two macro-areas (macro-area 1: Piacenza, Parma, and Reggio-Emilia; macro-area 2: Modena, Bologna, and Ferrara) (Table 1). The environmental and socio-demographic conditions of all the cities included in the analysis are very similar.

Mean daily apparent temperature, a composite index that takes into account both temperature and humidity,[12,13] was computed in order to synthesize stressful bioclimatic conditions. Meteorological data came from the network of urban meteorological stations placed with common criteria within each city.

Statistical analysis was performed in two stages. First, we performed a time series analysis for each city using generalized linear models (GLM) with natural spline smoothers to control for seasonal patterns and long-term trend. A quasi-Poisson distribution with over-dispersion was assumed for the daily number of EAD.

The average concentrations of PM_{10} in the same day and the day before the outcome were chosen as a time scale of exposure (lag 0–1).[1] The effect of PM_{10} on health in the model was adjusted for the day of the week as a factor, and influenza epidemics, holiday periods, and population decrease during August as dummy variables. Influenza epidemics were defined on the basis of the regional weekly estimates of flu incidence, as reported by the Italian National Institute of Health. A natural spline with city-specific degrees of freedom selected automatically by generalized cross-validation was used to control for the confounding effect of apparent temperature. Age-adjusted estimates were obtained, including a three-level factor (35–64, 65–74, and over 75) in the model. An interaction term between PM_{10} and an indicator function for the warm (from April to September) and cold (from January to March and October to December) seasons was added to the model in order to assess season-specific relative rates. Therefore, the city-specific GLM model is given by

$$\log[\mathrm{EAD_i}] = \beta_{0_i} + \beta_{1_i}\mathrm{PM}_{10_i} + \beta_{1_i}(\mathrm{weekday}) + \beta_{2_i}(\inf l) + \beta_{3_i}(\mathrm{holidays}) + \beta_{4_i}(\mathrm{age\ class}) + \beta_{5_i}\mathrm{PM}_{10_i} * (\mathrm{season}) + \mathrm{ns}_{1_i}(\mathrm{AT_i}, df = 5) + \mathrm{ns}_{2_i}(\mathrm{time},\ df = 2 * \mathrm{year})$$

where the subscript i refers to the ith city; β_{0_i} is the intercept; β_{j_i} are the regression coefficients associated to the covariates PM_{10} concentration (PM_{10_i}), day of the week (weekday), influence (infl), holidays (holidays), and age class (age class); $ns_{1_i}(\mathrm{AT_i}, df = 5)$ is the natural cubic spline function of apparent temperature with five degrees of freedom; and $\mathrm{ns}_{2_i}(\mathrm{time}, df = 2 * \mathrm{year})$ is the natural cubic spline function of calendar time with two degrees of freedom per year.

In the second stage, city-specific effects of PM_{10} were combined in fixed or random effect meta-analyses, depending on the Woolf's heterogeneity test among the cities (heterogeneity was assumed to be substantial if $P(\mathrm{het}) < 0.05$). An overall measure of effect was obtained using the maximum likelihood method.

Results

The number of EAD for the 35+ age group was 130.665. On average, non-traumatic diseases constituted 49.6% of the EAD taking into account the entire population, whereas the percentage increased to 75.8% for those aged 35 and older. Respectively, cardiovascular and respiratory diseases accounted for 12.8% and 8.9% of the total EAD (Table 2). The percentage was quite similar across the cities with the exception of Bologna and Ferrara, where the prevalence of cardiovascular diseases was significantly higher.

The concentrations of PM_{10} were very similar among macro-areas with mean values ranging from 40.2 to 41.9 μg/m^3 and 98° percentile ranging from 104 to 110 μg/m^3 (Table 3). We also found very limited variability within the macro-areas, with mean values ranging from 39 to 45 μg/m^3 (data not shown). The concentrations were about twice as high in the cold season compared to the warm season.

We did not find heterogeneity among the cities for any group of diseases, and fixed effects (Mantel Haenszel) meta-analyses were applied. The meta-analytic estimate of the percentage of increase in risk for a 10-μg/m^3 rise of PM_{10} for non-traumatic diseases was 0.86% (95% confidence interval (95%CI): 0.61,1.1) (Table 4). We also found increased EAD to be positively associated with day-to-day variations of PM_{10} for cardiovascular and respiratory diseases, but not with statistical significance. The coefficients for the two group of diseases were 0.31% (95%CI: −0.13,0.75) and 0.44% (95%CI: −0.02,0.91), respectively.

A relevant increase in risk for non-traumatic diseases was found in the warm season (2.33%, 95%CI: 1.61,3.04) compared to the cold season (0.58, 95%CI: 0.31,0.84). The same seasonal trend was evident for cardiovascular (1.79% vs. 0.1%) and respiratory diseases (1.33% vs. 0.28%).

Table 1 Number of urban background, residential background, and traffic PM_{10} monitoring stations selected for the study

	Monitoring stations			
City	Urban background	Residential background	Traffic	Total
Piacenza	1	0	1	2
Parma	0	1	0	1
Reggio-Emilia	1	1	1	3
Macro-area 1	2	2	2	6
Modena	0	1	0	1
Bologna	0	0	2	2
Ferrara	0	1	1	2
Macro-area 2	0	2	3	5
Study area	2	4	5	11

Figure 2 shows the forest plot of the city-specific estimates for the cold and the warm seasons. During the warm season, all estimates referred to non-traumatic and cardiovascular diseases were consistent and statistically significant across the cities. The estimates for the respiratory diseases were less consistent, producing a non-significant negative coefficient for Piacenza (the smallest city of the region). The findings for non-traumatic diseases during the cold season were reasonably homogeneous across the study area. Only the city of Modena showed a slightly negative coefficient. Larger differences across the study area were found for cardiovascular and respiratory diseases. For these groups of causes, the meta-analytic estimates were close to zero. Heterogeneity test showed not significant differences both for the warm and cold seasons. Meta-analytic estimates are mainly driven by the data from Bologna.

As expected, no significant effects were found for traumatic diseases (0.13, 95%CI: −0.27,0.54; *P*-value 0.739).

Discussion

The findings of our study indicate that particle pollution increases EAD for non-traumatic diseases. We also found some evidence of an association of day-to-day variations of PM_{10} with cardiovascular and respiratory-related dispatches. The results are quite coherent across the cities.

Larger risks were found for PM_{10} exposure during the warm season, despite the remarkably lower PM_{10} concentrations typical of the period. This effect of modification by season has also been reported in other studies on mortality,[14,15] and may be due to a seasonal trend in chemical composition of particles or due to differences in indoor exposure (e.g. increased natural ventilation in buildings).

A direct comparison of our findings with the literature is not feasible because we did not find other studies using such data. However, it is interesting to compare the associations found for EAD with that found for mortality and hospital admissions. Table 4 shows a comparison of our findings with those obtained in the main Italian meta-analysis on the short-term effects of air pollution using mortality and hospital admission data.[16,17] Italian results are well in agreement with the main international studies.[18] Overall, the order of magnitude of increase in risk associated with unit increases in PM_{10} concentrations is similar in terms of ambulance dispatches and mortality for all non-traumatic diseases. On the other hand, the association between ambulance interventions for cardiovascular and respiratory pathologies, while not significant and with quite large CIs, showed coefficients for increase in risk lower than risks found for both mortality and hospital admissions.

The EAD database proved a very interesting source of information. The first reason is because it is a novel indicator of acute events in relatively large numbers. The second important reason is that it is the only health indicator available in real time. We did not use the data in real time for our study because we were interested in understanding whether there was an association between EAD and particle concentrations. However, the real-time availability is probably the most interesting characteristic of these data because this allows their use in real-time surveillance systems.

Despite the suggestive potential of EAD database, there are also some important limitations. The first

Table 2 Descriptive statistics on study population and emergency ambulance dispatches (EAD)

City	Population	Population 35+ (%)	Daily mean EAD 35+	Non-traumatic EAD 35+ (%)	Cardiovascular EAD 35+ (%)	Respiratory EAD 35+ (%)
Piacenza	98 146	66 463 (67.7%)	19	76.6	10.7	9.0
Parma	172 637	138 752 (80.4%)	28	75.4	11.4	8.6
Reggio	152 899	92 727 (60.6%)	28	74.8	10.6	7.3
Modena	178 196	122 782 (68.9%)	31	76.1	10.3	9.4
Bologna	371 218	254 454 (68.5%)	73	76.6	17.5	9.3
Ferrara	130 972	92 322 (70.5%)	22	75.5	16.5	9.9
Total	1 104 068	768 500 (69.4%)	201	75.8	12.8	8.9

Table 3 Descriptive statistics on PM_{10} in the study area

City	Mean	Median	Minimum	Maximum	Interquartile range
Macro-area 1					
Piacenza	40.2	33.5	4.3	204.6	29.2
Parma					
Reggio-Emilia					
Macro-area 2					
Modena	41.9	36.1	6.2	208.0	25.7
Bologna					
Ferrara					

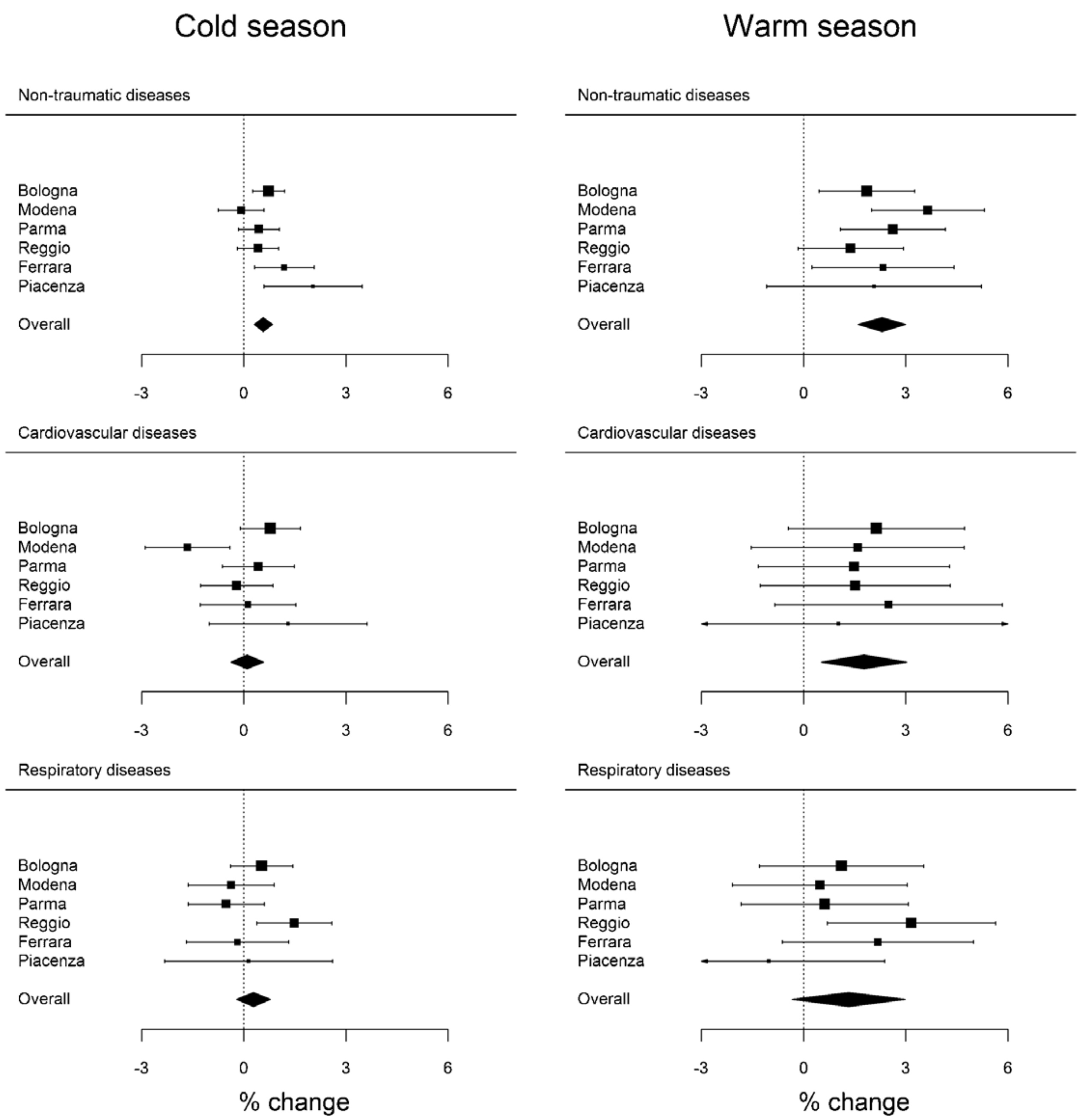

Figure 2 Forest plot of the city-specific and meta-analytic effects of 10 μg/m^3 increase of PM_{10} on EAD for the cold and the warm seasons.

limitation is that no personal identification field is available in the EAD database. For this reason, we were not able to link ambulance intervention to hospital admissions, mortality data, or any other health database. The second limitation is that the diagnoses are made via telephone interview. This approach enables only a rough classification of diseases, and it makes wrong diagnoses more frequent than for disease data derived from direct medical examinations. Is it possible that the higher

Table 4 Comparison between increase in EAD and increase in mortality and hospital admissions associated to 10 μg/m^3 increase of PM_{10} concentrations (lag 0–1). Mortality and hospital admission coefficients are derived from the main and most up-to-date Italian meta-analysis of the health effects of air pollution. Percent increase and 95% confidence intervals (95%CI) are reported

	EAD		Mortality		Hospital admissions	
Group of diseases	%	95%CI	%	95%CI	%	95%CI
Non-traumatic	0.86	(0.61,–1.1)	0.69	(0.40,–0.98)	/	/
Cardiovascular	0.31	(−0.13,–0.75)	0.99	(0.43,–1.54)	0.7	(0.40,–1.00)
Respiratory	0.44	(−0.02,–0.91)	1.59	(0.54,–2.66)	0.78	(0.40,–1.16)

effects found for non-traumatic diseases with respect to cardiovascular as well as respiratory diseases could be related to possible misclassification with respect to the groups of pathologies. This misclassification may have a larger impact on the elderly persons, who are often affected by concurrent pathologies and who are at higher risk of hospitalization or death in association with short-term variations of air pollution.

In conclusion, EAD are an important morbidity indicator that can provide broader insight into the health effects of particulate matter. Moreover, the real-time availability of these data for the entire Emilia-Romagna region enables their use in a surveillance system to monitor the effects of environmental risk factors on health such as the real-time syndromic surveillance system operating in England and Wales.[19]

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