The effect of airborne particles and weather conditions on pediatric respiratory infections in Cordoba, Argentine

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ABSTRACT

We studied the effect of estimated PM_{10} on respiratory infections in children from Cordoba, Argentine as well as the influence of weather factors, socio-economic conditions and education. We analyzed upper and lower respiratory infections and applied a time-series analysis with a quasi-Poisson distribution link function. To control for seasonally varying factors we fitted cubic smoothing splines of date. We also examined community-specific parameters and differences in susceptibility by sex. We found a significant association between particles and respiratory infections. This relationship was affected by mean temperature, atmospheric pressure and wind speed. These effects were stronger in fall, winter and spring for upper respiratory infections while for lower respiratory infections the association was significant only during spring. Low socio-economic conditions and low education levels increased the risk of respiratory infections. These findings add useful information to understand the influence of airborne particles on children health in developing countries.

1. Introduction

One of the major threats to human health in urban environments is airborne particulates. Numerous studies have been published on the risk associated with particles that are 10 μm diameter or less, while recent works, focused on particles that are 2.5 μm or smaller, found stronger evidence of an association with morbidity due to respiratory infections (Peng et al., 2008; Zanobetti et al., 2009). However, the bulk of the evidence on mortality and hospital admissions comes from studies of short-term exposures to lower concentrations of outdoor air pollution in developed countries (Braga et al., 2001; Zanobetti et al., 2000) A small number of studies have been conducted in developing countries (Romieu et al., 2002).

While many similarities exist in the constituents of air pollution around the globe (HEI, 2004), there are significant differences in the composition and size of urban particles due to their different emission sources. For instance, road dusts together with vehicle emissions are the primary source of particles in many urban environments from Latin American countries rather than fuel combustion. Such differences create uncertainties when foreign studies are used to estimate the impact of particulate matter on

health in a different country. In Argentine, as in many other Latin American countries, the environmental situation is an important factor impairing public health. In the last decades, a continuous deterioration of environmental quality had been observed, particularly in big cities, such as Cordoba. A previous work mentioned that the population is continuously exposed to high levels of air pollution, mainly particles coming from vehicles (Olcese and Toselli, 2002).

Acute respiratory infections are the largest single cause of mortality among young children worldwide and thus account for a significant global burden of disease worldwide (Williams et al., 2002). Although outdoor air pollution has been associated with increased respiratory infections mortality and with increased symptoms, admissions to hospitals, and ER visits, recent epidemiological data suggests a significant effect also of meteorological factors like temperature, humidity, rainfall, and atmospheric pressure in combination with pollution levels (Nastos and Matzarakis, 2006). The need for further understanding of the influence of meteorological variables on respiratory infections becomes more evident if someone considers the significant morbidity of these infections as well as their serious socio-economic consequences which are more evident in developing countries.

Several studies indicate that some segments of the population may be more susceptible to air pollutants than others (Kan et al., 2008). This susceptibility or vulnerability may result from disproportionate exposure; underlying medical or biological factors

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related to age, sex or disease status, access to other amenities (nutritious food, adequate water, vaccines, proper health care) and/or socio-economic status (Bateson and Schwartz, 2004; Cakmak et al., 2006). Differences in population susceptibility are of particular interest with increasing evidence that climate change will affect the most disadvantaged populations, amplifying social disparities in health, both within and between countries (Bell et al., 2008). Moreover, most of these studies were conducted in developed countries. Therefore, remains the need for studies of cities in developing countries, where characteristics of outdoor air pollution, meteorological conditions and socio-demographic patterns may differ from those in North America and Europe.

In the present study, we conducted a time-series analysis to examine the influence of airborne particles on children respiratory health of children from Cordoba, Argentine and to investigate the meteorological factors that influence this relationship as well as the modifying effect of season, sex, socio-economic status and education.

2. Materials and methods

2.1. Study area

The present study was undertaken in the city of Cordoba, located in the center of Argentina (31°24′S, 64°11′W) at an altitude of approximately 400 m above sea level. It has a population of 1.3 million and an irregular topography. Its general structure is funnel-shaped, with an increasing positive slope from the center toward the surrounding area. This somewhat concave formation reduces the air circulation and causes frequent thermal inversions both in autumn and winter. The climate is sub-humid, with an average annual rainfall of 790 mm, concentrated mainly in summer. The mean annual temperature is 17.4 °C and the prevailing winds come from the NE, S and SE.

The main sources of air pollution in the downtown area of Cordoba city are automobile sources (Stein and Toselli, 1996). The traffic pattern holds a strong relationship with primary pollutants (CO, NO_x and PM_{10}) which is another reason further justifying the assumption that the pollution in the city is mainly due to automobile sources (Olcese and Toselli, 2002). It is important to notice that the use of leaded gasoline in Argentina has now been reduced for over a decade; however, elevated levels of lead are still measured associated to soils near main roads (Pignata et al., 2007). The city also has an important industrial development of mainly metallurgic and mechanical industries.

2.2. Study population and health outcomes

Health information was obtained from the public system of medical care from the city of Cordoba, Argentine, which included 95 health care centers distributed all around the urban and suburban area of the city. The information included the location of the health center as well as the patient age, gender and principal diagnosis. Because personal identifiers were not available for individual patients, readmissions could not be identified and removed, therefore the data included all admissions assuming the fact that each admission is independent.

Although respiratory diseases are a major cause of morbidity worldwide, the rate of lower respiratory infections is higher in developing countries (Rosa et al., 2008). For our study the eligible study population included all patients younger than 6 years old diagnosed with upper or lower respiratory infections from January 1st, 2005 to December 31st, 2008. Respiratory infections were classified according to the International Classification of Diseases, 9th Revision (ICD-9 code) and diagnosed as common cold (J00), otitis (H65 and H66), pharyngitis (J02), sinusitis (J01) and laryngitis (J04), which were grouped as upper respiratory tract infections (URI) and bronchitis (J20 and J21) and pneumonia (J18) which were categorized as lower respiratory tract infections (LRI).

2.3. Meteorological data

Meteorological data were obtained from the meteorological station of the National Meteorological Service located at the airport of the city of Cordoba, 7 km north from the city center (−31.31° S, −64.21° W, altitude 484 m asl). Thus we checked the influence of mean (T), maximum (T_{max}), minimum (T_{min}) and apparent temperature (AT) as temperature exposure predictors, and relative humidity (H), atmospheric pressure (P) and wind speed (W), as well.

At the moment the study was done, there was no continuous information on pollutant concentrations in the city of Cordoba. Therefore, we modeled PM_{10} concentrations from data recorded by two monitoring stations that were functioning from June 1998 to September 1999 in downtown Cordoba. Thus, we used a regression model with linear terms for daily PM_{10}, temperature, relative humidity,

wind speed, visibility and day of the week. Scatterplots of observed and estimated values showed a good agreement and the correlation coefficient calculated was 0.82 (Fig. 1).

2.4. Statistical analysis

The association between the estimated PM_{10} and weather variables observed in Cordoba city and the number of admissions of children due to upper and lower respiratory diseases were modeled using Generalised Additive Models (GAM) using a quasi-Poisson regression as the link function. GAM try to model the relationship between an outcome, which, in the case of studies on air pollution and health, is usually the number of deaths or the number of hospitalizations for some specific disease and an exposure, in the presence of potential confounding factors (Peng et al., 2008). GAM is a semiparametric model where the outcome is assumed to be additive in its predictors, but not necessarily linear. With this type of model it is also possible to introduce possible measured and unmeasured confounders, i.e. other possible time-varying factors, beside the predictors, which could confound the relationship between the outcome and the predictors. The introduction of unmeasured confounders is very useful to fully understand the outcome variation and they can be included in the model through the assumption that these factors vary smoothly with time. Thus a smooth function of time can be used to serve as an approximation for the unmeasured confounders. Therefore, to control for seasonally varying factors we fitted cubic smoothing splines of date with equally spaced knots, with 3–4 df/year for these smoothing splines. This number of df was chosen as a compromise between providing adequate control for unmeasured confounders and leaving enough information to estimate particles and weather effects in the short term.

We used a dummy variable for weekday, to capture day of the week effects, i.e. hospital admissions showed a minimum of admissions on Sundays due to during weekends very few health care centers remained open.

We first compare models with different temperature exposure predictors, separately. Thus, we checked the effect estimates of mean, maximum, minimum and apparent temperature to ensure our results were robust. We then decided to use mean temperature since it was the parameter with the highest coefficient. After that, we conducted exploratory analyses to determine whether the use of linear terms for particle concentration and weather variables was appropriate. If the exploratory plots from those models looked roughly linear the variables were included in the main model as linear terms, which facilitate the reporting of odds ratios.

The model was build up entering the meteorological variables sequentially and including them in the model if they were significant predictors or confounders of the relationship between particles and respiratory infections. We checked the lagged effect of weather variables and particles up to 10 days before the event and included in the model only the lag with the strongest effect. All variables were included with lag 0 except for wind speed that was included with 2 days lag. The analyses were performed using statistical software R 2.12.1.

Seasonal patterns have been often observed in respiratory diseases, mainly upper respiratory infections (Bell et al., 2008; Makinen et al., 2009; Nastos and Matzarakis, 2006), therefore as secondary analysis we run a stratified analysis by season (summer, fall, winter and spring). Besides, as there is evidence that socio-economic status plays a role in the health effects of particles (Stafoggia et al., 2008; Zanobetti et al., 2009) we examined community-specific parameters including percent of population that attained different education levels and land use of the area where the health center is located. Also we investigated differences in susceptibility by sex. The results are reported as percent change in LRI and URI for a 10 $\mu g/m^3$ increase in particles concentration.
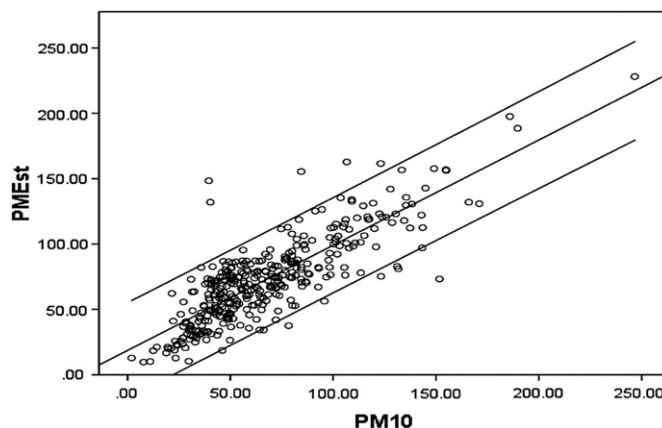

Fig. 1. Scatterplot of estimated vs measured PM_{10} (mean ± 95% CI).

3. Results

A total of 81,569 pediatric hospital admissions due to respiratory diseases during 2005–2008 were included in the analysis. Among them URI represented 42.5% and LRI represented 57.5%.

Daily concentrations of meteorological variables and PM_{10} during the study period are shown in Table 1. In Cordoba seasons are markedly different, while winters are dry, cold and windy, particularly in July and August, summers are very hot and humid and high T (>30 °C) are common since November to February.

The socio-economical characteristics of the population are given in Table 2. We observed that women were slightly more numerous than men. Regarding the level of education attained by adults, most of them finished the elementary school, a low proportion had no education at all and only a small portion finished university studies. We used maps published by the town city hall to classify the health centers according to the land use of the area where they were located. Most of the health centers are located in residential areas. Some others were actually located very close to industries since the original suburban place where the industries were built 40 years ago, is now a medium to high densely populated neighborhood. The newer health centers are the ones located in suburban areas (≥10 km from downtown) where there is still very low population density.

We then compared the association between particles and URI and LRI with and without weather adjustment. Table 3 shows the increased risk in upper and lower respiratory infections for a 10 μg/m³ increase in particles concentration with various degrees of weather variables adjustment. The effect estimate for particles increased when either pressure or wind were included in the model. However, the increase was more dramatically when temperature was included in the model for both, URI and LRI. Humidity showed a protective effect against respiratory infections and a high correlation coefficient with particles ($R = 0.8$), which suggest a covariation. Therefore, to avoid the effect of covariates it was not included in subsequent models which were all finally adjusted for temperature, wind speed and atmospheric pressure.

We run a stratified analysis by seasons, allowing a more specific control for season and trend (Fig. 2). We observed significant effects of particles in fall, winter and spring for URI, while the relationship of particles with LRI was significant only during spring.

Table 4 compares morbidity risk for respiratory infections for a 10 μg/m³ increase in PM_{10} concentration by sex, education attainment and land use. No consistent trend was observed for the association between PM_{10} and sex, since effect estimates for men and women were almost the same. The association between education level and respiratory infections showed the highest effect estimates for the least educated in both URI and LRI. However, positive associations were observed for those with the highest education level (university), too. In our study we employed land use categories to estimate not only the economic status of the community living near the health centers but also their exposition to air pollutants. Thus, people living in industrial areas are possibly more exposed to particles emitted by anthropogenic sources than people living in rural areas where the main composition of particles

is natural dust blown up by wind. Although we found positive effects in all categories, the highest risk for URI and LRI was observed in people living near industries and the lower one in people living in rural areas.

4. Discussion

We found a significant association between particles and respiratory infections in children from Cordoba, Argentina, in agreement with results presented by Nastos et al. (2010) and Samoli et al. (2011). Importantly, we observed a significant confounding effect of mean temperature and atmospheric pressure and also a significant effect of wind speed. These effects were stronger in fall, winter and spring for URI while for LRI the association was significant only during spring. Moreover, these effects were affected by socio-economic conditions and education levels of the population.

In 1218 days (1.5%) the estimated mean values of PM_{10} were higher than the corresponding EU limit values for a 24 h period (50 μg/m³). However, most of these values were lower than the average daily values (107.3 μg m³ and 101.1 μg m³) measured by López et al. (2011) in two sampling sites in Cordoba city, which suggest that we underestimated the real concentration of particles. Even though these difference, we believe the results of the present work can be used as reference for future epidemiological studies.

Numerous studies analyzed the relationship between weather factors and airborne particles. However, as many aspects of weather affect air quality, the role of each aspect separately is not that clear (D'Amato et al., 2002). Some studies did not found any confounding effect between particles and weather factors (Basu et al., 2008); some others found a small decrease in mortality when including ozone or PM_{10} in the model (O'Neill et al., 2003); while others found an increase in the association of respiratory admissions with temperature when including PM_{10} in the model (Ren and Tong, 2006). In our study we observed positive associations between particles and weather factors that confirm the need to carefully

Table 2
Socio-economical characteristics of the study population in Cordoba, Argentine.

Sex (%)	
Male	46.3
Female	53.7
Education[a]	
None	2.58
Elementary	23.91
Secondary	13.10
University	7.06
Land use[b]	
Residential	73.5
Rural	11.0
Industrial	15.5

[a] % of adults (>15 years old) that completed each level.
[b] % of health centers on each category.

Table 1
Daily descriptive statistics of the meteorological variables for the period 2005–2008 in Cordoba, Argentine.

	Mean	SD	Min	Max
Meteorological variables				
T (°C)	17.34	5.63	0.10	30.70
P (hP)	1016.7	5.66	1004.0	1039.0
W (km/h)	13.39	5.03	4.40	38.00
PM_{10} est (μg/m³)	65.61	15.46	26.72	122.02

Table 3
Percentage increase in risk of upper (URI) and lower (LRI) respiratory infections (95% CI) for every 10 μg/m³ increase in particles (PM_{10}), for various adjustments time series models.

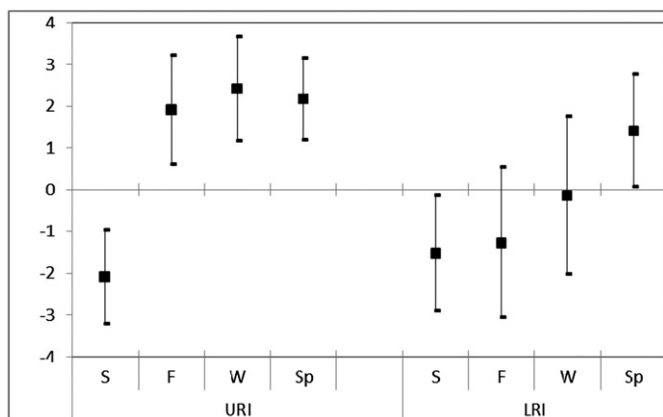|	URI			LRI		
	% Change	95% CI		% Change	95% CI	
PM_{10}	1.91	1.48	2.35	0.77	0.19	1.35
$PM_{10} + T$	3.55	3.09	4.01	4.20	3.58	4.81
$PM_{10} + H$	−2.40	−3.16	−1.65	−2.70	−3.71	−1.69
$PM_{10} + W$	3.16	2.62	3.70	3.05	2.33	3.77
$PM_{10} + P$	2.31	1.87	2.75	1.44	0.85	2.02
$PM_{10} + T + W + P$	4.49	3.93	5.05	5.61	4.87	6.35

Fig. 2. Percent increase in risk of upper (URI) and lower (LRI) respiratory infections (±95% CI) for every 10 μg/m^3 increase in PM$_{10}$, during summer (S), fall (F), winter (W) and spring (Sp).

consider the role of these parameters when estimating airborne particles effects. Similar results have also been found by Soebiyanto et al. (2010) who showed that including the environmental variables increased the prediction capability of the model used to predict influenza transmission. Differences between our study and others in terms of whether to include or not weather variables in the model could be due to several reasons such as different type of modeling, different outcomes or target population and different weather factors/particles effect in different regions (Zanobetti and Schwartz, 2008).

Weather conditions are a significant driver of respiratory infections (Danielides et al., 2002). A previous study made in Buenos Aires found an increase in lower respiratory infections in children under 5 years old, during wintertime (Viegas et al., 2004). Similarly, Goncalves et al. (2005) in Sao Paulo, found a decrease in respiratory morbidity under hot and dry weather conditions. In agreement, our study showed that the highest risk for URI was during winter, but we found a significant risk during fall and spring, too. Numerous studies have proved that URI are affected by low temperature. However the reasons for this seasonality are still controversial because many different social and biological factors contribute to the increase incidence of these diseases during the winter months, such as the crowding promotes the transmission, breathing cold air causes drying of the mucosal membrane and even low temperatures favor the survival of pathogens. Considering the season's characteristics of Cordoba city, the results of the sensitivity analysis suggest that viral infections and airborne particles are probably responsible for the peak in fall and winter;

Table 4
Percentage increase in risk of upper (URI) and lower (LRI) respiratory infections (95% CI) for every 10 μg/m^3 increase in particles (PM$_{10}$) by sex, land use and education.

	URI			LRI		
	% Change	95% CI		% Change	95% CI	
Sex						
Male	3.44	2.93	3.95	3.21	2.85	3.88
Female	3.46	2.97	3.95	3.28	2.87	3.90
Education						
None	4.59	4.13	5.05	5.61	4.98	6.24
Elementary	3.59	3.13	4.06	4.60	3.97	5.23
Secondary	3.02	2.94	3.66	4.63	4.01	5.26
University	2.56	2.10	2.93	2.11	1.98	2.29
Land use						
Residential	1.32	1.11	1.57	1.52	1.26	1.92
Rural	0.98	0.85	1.05	0.78	0.70	0.89
Industrial	2.28	1.45	2.87	1.88	1.69	1.97

whereas during spring, the incidence of upper respiratory infections is mainly associated with pollen allergy. On the other hand, the presence of particles was a significant risk factor for LRI only during spring. The differences observed are possibly due the different etiological pattern of the development of LRI, since these infections are not temperature sensitive as a primary infection, and are also predetermined by host factors, such as immunological defense mechanisms and genetic susceptibility (Makinen et al., 2009). The fact that we found a higher effect estimate of wind speed in the preceding 2 days before the event is also mentioned by Berktas and Bircan (2003) and is probably related to differences in barometric pressure. Indeed, in the present study atmospheric pressure appeared to play a significant role, since an increase in risk was observed when we included this factor in the model. According to Hashimoto et al. (2004) a rapid decrease from higher barometric pressure exacerbates respiratory infections in children. However, we believe that it is not easy to evaluate the impact of a specific meteorological variable on hospital admissions or emergency room visits, most likely because of the interaction of the various implicated factors.

Sex differences in response to infections have been observed in several studies in adults (Gleeson et al., 2011). Since these differences are based on the immune response of an individual which is highly related to hormones (Beery, 2003), it is unlikely to observe such differences in young children. In fact, we did not found any differences between sex, which is probably related to both the similar exposition pattern in children, in opposition to adults whose exposition is often related to work, and the similar resistance to infections in young children.

Education alone is one of many factors relating to overall socio-economic position. It is a predictor for the knowledge people possess and for the income they are likely to gain. We found high upper and lower respiratory infections risk in those communities with the higher percentage of adults without formal education, while the other education categories had almost the same effect estimate. It has been previously reported that children of mothers with lower educational levels are in poorer health than children of the most highly educated mothers (Ruijsbroek et al., 2011). Bell et al. (2008) also found high vulnerability in people with less education living in Sao Paulo, but different trends with data from Mexico DF and Santiago. The authors attributed these differences to variations in the role of socio-economic factors in each city, which reinforce the idea that results are not applicable to foreign cities.

It is already known that those who are socio-economically better off are generally in better health (Ruijsbroek et al., 2011). Indeed, previous studies found that socio-economic factors affect vulnerability to respiratory infections (Nastos and Matzarakis, 2006; Ruijsbroek et al., 2011). However, the relationship between socio-economic factors and health had been much less-studied for Latin−American countries than for more developed regions. Even though the nature of susceptibility by socio-economic position is far more complex that can be captured by the single markers we used, we wanted to explore this association because there is no previous work on this issue in Argentine and other indicators for family socio-economic background were not available. Our results showed a higher risk of respiratory infections in children living near industries and the lowest risk in children living in rural areas. In agreement, previous studies indicated that rural coarse particulate matter poses less health risk than urban particulate matter, probably because their different origin: in urban environments, particles are influenced by transportation whereas in rural environments agriculture practices, unpaved roads, construction sites and wind are key influences (Ostro et al., 2000). In our study, the communities living in rural suburban areas are probably the ones

with the lowest income. The fact that we found higher risk in children from communities located near industries, suggests that the exposition to industrial pollutants is a stronger risk factor than socio-economic conditions by itself.

A key limitation of this study is the fact that we don't have real PM_{10} concentrations. The fact that we found evidence of adverse health effect on children even when estimated PM_{10} concentrations are probably underestimated, suggest that particle's effect could be much stronger that what we found. This is a fully justified reason to establish a continuous particle-monitoring network in the city of Cordoba, to measure not only PM_{10} but also $PM_{2.5}$ concentration. Another disadvantage of the study is that we used only a small portion of the population, though probably the most vulnerable, but we cannot extrapolate the results to the entire city. Also, the present study was aimed to get baseline data; therefore we grouped several types of respiratory infections into 2 main categories (upper and lower) that may prevent the identification of stronger or weaker associations with the various types of diseases. We also acknowledge that this is a retrospective study and therefore is inherently subject to limitations such as misclassification of cases.

Despite these limitations, our findings add useful information to understand the association and its modifying factors between airborne particles and children health in a city from a developing country with few existing studies. Understanding the nature of vulnerable populations with respect to pollution events and the meteorological factors that contribute to the burden of the disease is of critical importance to guide efforts to reduce the serious respiratory morbidity in children and various consequences associated with these infection. More attention is needed to find effective ways of promoting a healthier lifestyle among parents and prospective parents from lower socio-economic backgrounds so that health disparities throughout the life course can eventually be tackled.

Acknowledgments

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