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Effects of air pollution on infant and children respiratory mortality in four large Latin-American cities☆

Nelson Gouveia [a, *], Washington Leite Junger [b] On behalf of the ESCALA investigators

[a] Departamento de Medicina Preventiva, Faculdade de Medicina, FMUSP, Universidade de São Paulo, Av Dr Arnaldo, 455, Sao Paulo, 01246-903, Brazil
[b] Instituto de Medicina Social, Universidade do Estado do Rio de Janeiro, UERJ, Rio de Janeiro, Brazil

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ABSTRACT

Objectives: Air pollution is an important public health concern especially for children who are particularly susceptible. Latin America has a large children population, is highly urbanized and levels of pollution are substantially high, making the potential health impact of air pollution quite large. We evaluated the effect of air pollution on children respiratory mortality in four large urban centers: Mexico City, Santiago, Chile, and Sao Paulo and Rio de Janeiro in Brazil.
Methods: Generalized Additive Models in Poisson regression was used to fit daily time-series of mortality due to respiratory diseases in infants and children, and levels of PM_{10} and O_3. Single lag and constrained polynomial distributed lag models were explored. Analyses were carried out per cause for each age group and each city. Fixed- and random-effects meta-analysis was conducted in order to combine the city-specific results in a single summary estimate.
Results: These cities host nearly 43 million people and pollution levels were above the WHO guidelines. For PM_{10} the percentage increase in risk of death due to respiratory diseases in infants in a fixed effect model was 0.47% (0.09–0.85). For respiratory deaths in children 1–5 years old, the increase in risk was 0.58% (0.08–1.08) while a higher effect was observed for lower respiratory infections (LRI) in children 1–14 years old [1.38% (0.91–1.85)]. For O_3, the only summarized estimate statistically significant was for LRI in infants. Analysis by season showed effects of O_3 in the warm season for respiratory diseases in infants, while negative effects were observed for respiratory and LRI deaths in children.
Discussion: We provided comparable mortality impact estimates of air pollutants across these cities and age groups. This information is important because many public policies aimed at preventing the adverse effects of pollution on health consider children as the population group that deserves the highest protection.

1. Introduction

Air pollution has become an important public health concern for most cities in the world. Evidence is mounting that exposure to ambient levels of air pollution has several health impacts ranging from cause-specific mortality and morbidity in adults and the elderly (Brunekreef and Holgate, 2002; Kampa and Castanas, 2008) to impacts in early life (Hajat et al., 2007) and during pregnancy (Dadvand et al., 2013).

Infants and children make up a particularly susceptible population to the health effects of air pollution. Lungs continue to develop after birth and while immature are less able to deal with toxic damages (Dixon, 2002; Pinkerton and Joad, 2000; Schwartz, 2004). In addition, this population is proportionally more exposed than adults to ambient air pollution due to longer periods spent outdoors, higher ventilation rates and mouth breathing, factors that increase their intake of air pollutants (Bateson and Schwartz, 2008; Dixon, 2002; Gilland et al., 1999; Schwartz, 2004; WHO, 2005).

The consequences of exposure to air pollution during early life include impairment of lung function (Harding and Maritz, 2012), increased risk of respiratory illness (Xiao et al., 2016) and a higher probability of premature mortality (Yorifuji et al., 2016; Hajat et al., 2007). Evidence indicates that these impacts continue up to later life and adulthood (Osmond and Baker, 2000) which justifies the

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* Corresponding author.
E-mail address: ngouveia@usp.br (N. Gouveia).

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increasing global concern about exposure to air pollution in this period of life.

However, there are relatively few studies that have examined the effect of air pollution on mortality during childhood, and those who have tried to examine this association may not have had sufficient statistical power due to the small number of events (Bhaskaran et al., 2013), a feature that is common to most cities of developed countries, where infant and child mortality is low (UNICEF, 2014). Therefore, large developing country cities, such as those in the Latin America Region, constitute an ideal scenario to evaluate the mortality effects of pollution for different specific causes in this age group.

Latin America has a very large children population (nearly 9% of the total population in the region or more than 53 million people is under 5 years old), is highly urbanized (over 80% of the population reside in urban settings) (UN-DESA, 2015) and urban levels of air pollution are amongst the higher in the world, making the potential health impact on children related to air pollution quite large.

We evaluated the effect of air pollution on infant and children mortality in four large urban centers in Latin America: Mexico City (21 million habitants) in Mexico, Santiago (5 million habitants), Chile, and Sao Paulo (11 million habitants) and Rio de Janeiro (6 million habitants) in Brazil. By using a common analytical approach, we aimed at providing comparable mortality impact estimates of air pollutants across these cities in these age groups. This information is important because many public policies aimed at preventing the adverse effects of environmental factors on health consider children as the population group that deserves the highest level of protection (WHO, 2005). This study is an extension of the Multicity Study of Air Pollution and Mortality in Latin America (the ESCALA Study) supported by the Health Effects Institute.

2. Methods

A daily time-series study of air pollution and infant and children mortality spanning the years 1997–2005 was conducted in Sao Paulo and Rio de Janeiro, Brazil, Santiago, Chile, and Mexico City, Mexico. This analysis was part of the ESCALA study (Estudio de Salud y Contaminación Atmosférica en Latino America) funded by the Health Effects Institute (Romieu et al., 2012).

Details of the data collected and the analytical approach used can be obtained elsewhere (Romieu et al., 2012). In summary, we examined daily counts of deaths due to respiratory diseases (International Classification of Diseases 10^{th} revision – ICD10 J00-J98) in infants (<1 year old) and children 1–5 years old, and of lower respiratory infections (LRI) ([ICD10] J10-J22) in infants and children 1–14 years old with daily levels of PM_{10} and O_3 in the four cities. For LRI we extended the age group up to 14 years old in order to increase de daily number of events.

We obtained air pollution measurements and mortality data following a standardized protocol and examined the data extensively to ensure comparability among the cities. Daily 8-hr maximum moving average for O_3 and daily 24-hr mean average of PM_{10} were calculated averaging measurements from all monitoring stations in each city. We examined only PM_{10} and O_3 due to data availability and scientific interest. PM_{10} was by far the most common measured pollutant in the cities analyzed, and both PM_{10} and O_3 have been the focus of most studies due to their potential for oxidative stress (Brunekreef and Holgate, 2002). We also considered in the analysis daily mean values of temperature and humidity using natural splines initially with 3 or 6 d.f., each at lags 0, 1, 2, and 3, and then using moving averages.

Following the study protocol agreed upon by researchers of the ESCALA study, we performed the city-specific analysis using Generalized Additive Models (GAM) in Poisson regression to fit the time-series data, according to the equation:

$$\ell n(E(Y_t)) = \beta X_{1t} + \sum_{i=2}^{p} S_i(X_{it})$$

where Y_t and X_{1t} are the number of deaths and levels of air pollution at day t, respectively; X_{it} are the predictor variables, which include time trends and seasonality, and S_i are the smoothing functions using natural splines. Indicator variables for day-of-week and national or local bank holidays were also included to account for the short term cyclic fluctuations in the data.

In the modeling process, we relied on model diagnostics choosing the number of degrees of freedom needed to minimize the Akaike Information Criterion (AIC) and to optimize the Partial Auto Correlation Function (PACF). We also checked the standardized deviance residuals for each meteorological indicator before and after its inclusion in the model.

After building a core model for each city, air pollution levels were introduced in lags of up to three days (single lag models-SLM) and also examining the cumulative effect using constrained polynomial distributed lag models (DLM) (Schwartz, 2000). This later model used a 2-degree polynomial structure with exposure to air pollution consisting of the same day up to lags of 3 days; only the overall effect is reported. Besides considering the latency of the effect of the pollutants, the DLM minimizes the instability in the estimation process, typical of the analyzes that use multiple lags.

The analyses were carried out per cause of death for each age-group. Risk estimates were calculated by introducing the air pollution variables into the models as linear terms and we present them as percentage relative risks for each increment of 10 $\mu g/m^3$ at PM_{10} or O_3 levels assuming a significance level of 5%.

Additional analyses of O_3 concentrations were stratified by season to account for the high seasonal variation of this pollutant. Because of the different geographical position of each city, “warm season” and “cold season” were defined in different ways, with warm season spanning from October to March and cold season from April to September in Sao Paulo, Rio and Santiago, and the opposite for Mexico City.

Finally, fixed- and random-effects meta-analysis was conducted in order to combine the city-specifics results in a single quantitative summary estimate (DerSimonian and Laird, 1986) for each outcome. All analyses were conducted using the software R version 2.15.1 (R Core Team, 2017). A library for R named *ares* was developed for the ESCALA study mostly based on the following R packages: gam, mgcv, stats, splines, and meta.

3. Results

The time series data analyzed spanned a period of 5 years for Rio de Janeiro (2001–2005), 8 years for Sao Paulo (1998–2005) and 9 years for Santiago and Mexico City (1997–2005).

Despite these being the largest cities in Latin America with a considerable children population, the daily number of infants and children deaths by respiratory diseases was low, especially when examining the lower respiratory infections (LRI) subgroup (Table 1). Mexico City presented the highest mean count for respiratory infant mortality (1.8 deaths/day) and Santiago the lowest (0.13 deaths/day).

Mean levels of PM_{10} in these cities varied from 46.7 $\mu g/m^3$ in Sao Paulo to 78.4 $\mu g/m^3$ in Santiago, while for O_3 values ranged from 28.1 $\mu g/m^3$ in Rio to 138.6 $\mu g/m^3$ in Mexico City. As expected, levels of O_3 were higher during the warm season for all cities. Nonetheless, levels of PM_{10} also varied by season being higher during the

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