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Air pollution, $PM_{2.5}$ composition, source factors, and respiratory symptoms in asthmatic and nonasthmatic children in Santiago, Chile

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ABSTRACT

The objective of this study was to determine the association of respiratory symptoms and medication use and exposure to various air pollutants, $PM_{2.5}$ components, and source factors in a panel of asthmatic and nonasthmatic children in Santiago, Chile. To this end, 174 children (90 asthmatics and 84 nonasthmatics) were followed throughout the winter months of 2010 and 2011. During the study period, children filled out daily diaries to record respiratory symptoms and medication use. Air pollution data were obtained from government central site measurements and a $PM_{2.5}$ characterization campaign. $PM_{2.5}$ source factors were obtained using positive matrix factorization (PMF). Associations of symptoms and exposure to pollutants and source-factor daily scores were modeled separately for asthmatic and nonasthmatic children using mixed logistic regression models with random intercepts, controlling for weather, day of the week, year, and viral outbreaks.

Overall, high concentrations of air pollutants and $PM_{2.5}$ components were observed. Six source factors were identified by PMF (motor vehicles, marine aerosol, copper smelter, secondary sulfates, wood burning, and soil dust). Overall, single pollutant models showed significant and strong associations between 7-day exposures for several criteria pollutants ($PM_{2.5}$, NO_2, O_3), $PM_{2.5}$ components (OC, K, S, Se, V), and source factors (secondary sulfate) and coughing, wheezing and three other respiratory symptoms in both in asthmatic and nonasthmatic children. No associations were found for use of rescue inhalers in asthmatics. Two-pollutant models showed that several associations remained significant after including $PM_{2.5}$, and other criteria pollutants, in the models, particularly components and source factors associated with industrial sources.

In conclusion, exposure to air pollutants, especially $PM_{2.5}$, NO_2, and O_3, were found to exacerbate respiratory symptoms in both asthmatic and nonasthmatic children. Some of the results suggest that $PM_{2.5}$ components associated with a secondary sulfate source may have a greater impact on some symptoms than $PM_{2.5}$. In general, the results of this study show important associations at concentrations close or below current air quality standards.

1. Introduction

Exposure to air pollutants can cause a large variety of health problems, ranging from minor physiological and biochemical changes to symptom exacerbation, increased rates of hospitalizations, and higher risks of mortality. This has led governments and international organizations to set standards and guidelines for the so-called criteria pollutants, i.e., air pollutants that are ubiquitous and are of public health concern (Holgate et al., 1999; U.S. Environmental Protection Agency, 2009; World Health Organization, 2005). The effects of these air pollutants on children's respiratory health have been a focus of research for several decades (Goldizen et al., 2016). Panel studies have been used to link acute exposure to air pollution with increased respiratory symptoms, medication use, changes in lung function and airway inflammation, with larger associations observed for $PM_{2.5}$, ozone, and nitrogen dioxide (Barraza-Villarreal et al., 2008; Delfino et al., 2004; Delfino et al., 2003; Delfino et al., 2002; Escamilla-Nunez et al., 2008; Li et al., 2012).

Air pollutants, including $PM_{2.5}$, are emitted from a large variety of sources such as power plants, gasoline and diesel vehicles, wood burning, and smelters. In turn, $PM_{2.5}$ is a mixture of many different

Abbreviations: As, arsenic; Cl, chlorine; CO, carbon monoxide; EC, elemental carbon; Fe, iron; IQR, interquartile range; K, potassium; Mo, molybdenum; NO_2, nitrogen dioxide; O_3, ozone; OC, organic carbon; Pb, lead; $PM_{2.5}$, particulate matter smaller than 2.5 µm; $PM_{2.5-10}$, particulate matter between 2.5 and 10 µm; PM_{10}, particulate matter smaller than 10 µm; PMF, positive matrix factorization; RH, relative humidity; S, sulfur; Se, selenium; SES, socioeconomic status; Si, silicon; SO_2, sulfur dioxide; V, vanadium.

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pollutants, with its composition varying depending on the relative contribution of these sources and their emission profiles. Statistical methods, such as factor analysis, use the temporal variation in composition to infer the relative contribution of these sources. Positive matrix factorization (PMF) (Hopke, 2016; Hopke and Cohen, 2011) is one of the most applied factor analysis methods and has been extensively used in several cities around the world, including in several in Chile (Ducret-Stich et al., 2013; Jorquera, 2009; Jorquera and Barraza, 2012; Yue et al., 2008).

From a policy perspective, it is important to identify which sources might produce the greatest impact on health. Some of these impacts can be estimated by assessing the associations of individual pollutants (such as NO_2 or SO_2) on health outcomes. However, the situation is more complex for $PM_{2.5}$, as its composition and toxicity might vary with different source contributions (National Research Council, 1998; U.S. Environmental Protection Agency, 2009; World Health Organization, 2005). Researchers, therefore, face the following related questions: (i) Which components of $PM_{2.5}$ are the most toxic? (ii) Which sources of $PM_{2.5}$ contribute the most toxic components? Approaches to address these issues include (i) toxicological testing of individual components of $PM_{2.5}$ (Amdur et al., 1952; Anderson et al., 1992; Utell et al., 1983); (ii) toxicological testing of surrogates of $PM_{2.5}$ emissions, such as residual oil fly ash (Dreher et al., 1997; Kodavanti et al., 2002; Kodavanti et al., 1996); (iii) toxicological testing of artificial atmospheres based on individual pollution sources such as vehicles or power plants, ideally with simulated atmospheric reactions (Diaz et al., 2012; Godleski et al., 2011; Lemos et al., 2011; Mauderly et al., 2011; Ruiz et al., 2007); and (iv) performing epidemiological studies to examine associations between $PM_{2.5}$ components and/or source factors and health problems. This last approach has been applied extensively in time-series studies, but results have not been clear in pointing to any particular source. Some review articles point to traffic source factors as the ones with stronger associations (Lippmann et al., 2013; Rohr and Wyzga, 2012; Stanek et al., 2011), while others to industrial ones (Adams et al., 2015). In Chile, time-series studies of mortality (Cakmak et al., 2009a; Valdes et al., 2012) and emergency room visits (Cakmak et al., 2009b) have also reported inconsistent findings. In the case of children's respiratory health, only a few panel studies have examined $PM_{2.5}$ components and source factors (Gent et al., 2009; Habre et al., 2014; Patel et al., 2013; Patel et al., 2011; Patel et al., 2010; Patel et al., 2009; Rohr et al., 2014).

Santiago is a city of 6 million inhabitants, located in a valley. During winter, the city typically experiences serious episodes of air pollution, including very high concentrations of particulate matter (Jorquera and Barraza, 2012; Koutrakis et al., 2005; Sax et al., 2007; Suarez et al., 2014). Several epidemiological studies have found that exposure to air pollutants has serious health consequences for the population of Santiago (Cifuentes et al., 2000; Franck et al., 2015; Franck et al., 2014), including children (Ilabaca et al., 1999; Pino et al., 2004). Due to the variety of source factors identified in Santiago (traffic, smelters, sulfates, and wood-burning heaters) and high concentrations of pollutants (Jorquera and Barraza, 2012), the setting provides an opportunity to study the associations between $PM_{2.5}$ composition and source factors on pediatric health. Here, we report the results for respiratory symptoms and medication use from a panel study conducted in Santiago, Chile. We particularly focus on determining whether any $PM_{2.5}$ component or source factor has a stronger association with health effects than $PM_{2.5}$ or other criteria pollutants (e.g., ozone, nitrogen oxide) (Holgate et al., 1999; World Health Organization, 2005). Additionally, we analyzed asthmatic and nonasthmatic children separately, as they can present different sensitivity to air pollutants and they might be the target of differential actions in response to air pollution episodes.

2. Methods and materials

2.1. Study design

This is a panel study, in which groups of asthmatic and nonasthmatic children were followed during the high-pollution winter months (May–September) of 2010 and 2011. Air pollution data were obtained from government monitoring sites, and a $PM_{2.5}$ characterization campaign carried out at university facilities. Children were recruited from two neighboring municipalities (Independencia and Recoleta) located about 5 km north of downtown Santiago and near the university and health service facilities where sampling and recruiting took place (Fig. 1). Most participants lived and studied close to the sampling sites (<3 km), thus improving exposure assessment by decreasing spatial variability. During the study period, respiratory health was assessed through symptom and medication use diaries, along with testing of lung function and airway inflammation. The latter two outcomes will be reported in a following article.

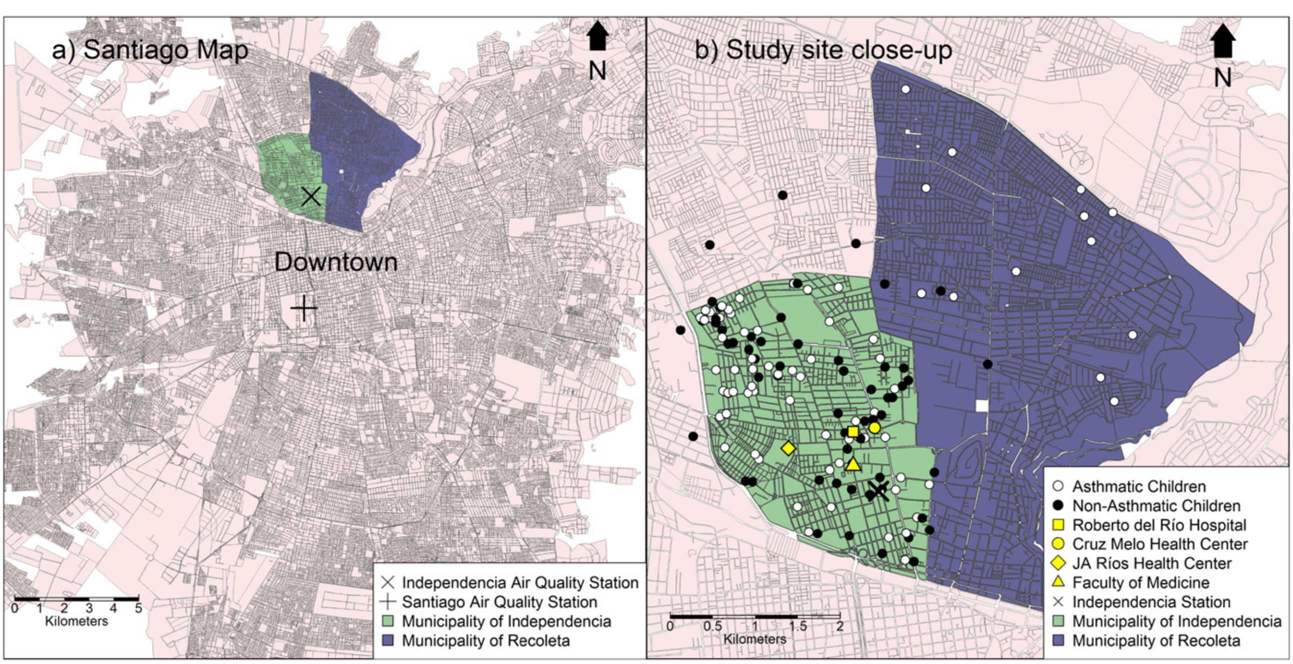

Fig. 1. Map of study locations.