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Multiple exposures to airborne pollutants and hospital admissions due to diseases of the circulatory system in Santiago de Chile

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HIGHLIGHTS

- We assessed the effects of multiple airborne exposures on cardiovascular hospital admissions in Santiago de Chile.
- We found significant adverse effects for CO, NO_2, PM10 and PM2.5, but not O_3.
- Effect strength and lag time depend on the type of pollutant.
- Different airborne pollutants account for varying adverse effects within different cardiovascular disease groups.

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ABSTRACT

Background: High concentrations of various air pollutants have been associated with hospitalization due to development and exacerbation of cardiovascular diseases.
Objectives: We aimed to assess associations between airborne exposures by particulate matter as well as gaseous air pollutants and hospital admissions due to different cardiovascular disease groups in Santiago de Chile.
Methods: The study was performed in the metropolitan area of Santiago de Chile during 2004–2007. We applied a time-stratified case-crossover analysis taking temporal variation, meteorological conditions and autocorrelation into account. We computed associations between daily ambient concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM10 and PM2.5 — particulate matter with aerodynamic diameters less than 10 or 2.5 μm, respectively) or ozone (O_3) and hospital admissions for cardiovascular illnesses.
Results: We found for CO, NO_2, PM10 and PM2.5 adverse relationships to cardiovascular admissions while effect strength and lag depended on the pollutant and on the disease group. By trend, in 1-pollutant models most adverse pollutants were NO_2 and particulate matter (PM10 and PM2.5) followed by CO, while in 2-pollutant models effects of PM10 persisted in most cases whereas other effects weakened. In addition the strongest effects seemed to be immediate or with a delay of up to 2 days. Adverse effects of ozone could not be detected.
Conclusions: Our results provided evidence for adverse health effects of combined exposure to airborne pollutants. Different pollutants accounted for varying adverse effects within different cardiovascular disease groups. Taking case numbers and effect strength of all cardiovascular diseases into account, mitigation measures should address all pollutants but especially NO_2, PM10, and CO.

1. Introduction and aim of the study

1.1. Air pollution in Santiago de Chile

Santiago de Chile, with more than 6 million inhabitants, suffers from high contamination levels due to relatively high emissions and unfavorable atmospheric and geographic conditions. During winter, the main contamination is due to primary emissions: particulate matter, sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). An important source of air pollution in Santiago de Chile is urban traffic (Cakmak et al., 2009; Moreno et al., 2010). These sources, together with high sun radiation during summer and orographic conditions, dominate the combined exposure of the population of Chile's capital (Suppan et al., 2012).

In 1997, the Metropolitan Area of Santiago de Chile was declared saturated zone for carbon monoxide (CO), particulate matter smaller than 10 μm in diameter (PM10), and ozone (O_3) (Gautam and Onursal, 1997). Whereas elevated concentrations of CO and PM10 can be observed during winter time, elevated ozone concentrations are typical around summer time. The national threshold for ozone of 120 $\mu g/m^3$ (eight hour mean value) was exceeded at least at one

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monitoring station inside the city at about 40% of the days per year. The reason for the high ozone concentrations is due to the high amounts of anthropogenic emissions and the photochemical activity, driven by the intense global radiation at this latitude. Pollutant concentrations have been decreased in the years after 1990 due to pollution reduction programs, especially the ones related to transport (Sax et al., 2007). Chile is one of the most urbanized countries in South America with almost 90% of the population residing in large urban areas. Thus, the quality of the environment in the cities has a strong impact on the health of the majority of the population. Since 1980, the rapid growth of the Chilean economy has adversely impacted the air quality in many urban areas (Kavouras et al., 2001).

Various pollutants have different natural and anthropogenic sources. Thus, mitigation strategies depend on the type of pollutant. Identification of most adverse pollutants and mixtures of pollutions may help to achieve the optimal cost–benefit ratio for the protection of human health. Therefore, the aim of the study was to identify harmful pollutants for development or exacerbation of different cardiovascular diseases.

1.2. Cardiovascular health effects of the investigated air pollutants

A number of studies have demonstrated the detrimental effects of ambient particulate matter on cardiovascular health (Barnett et al., 2006; Brook et al., 2010). Particulate matter has been found to be associated with increasing blood pressure, especially in persons with pre-existing conditions (Brook and Rajagopalan, 2009; Ibald-Mulli et al., 2004) and hypertensive crisis (Franck et al., 2011). Numbers of hospital admissions increase with increasing exposure to PM, NO_2, CO, and O_3 (Ballester et al., 2006; Barnett et al., 2006; Bell et al., 2009; Bener et al., 2009; Chen et al., 2010). Former investigations also suggested that air pollution arising from common emission sources for CO, NO_2, and PM (e.g., motor vehicle exhausts) has significant associations with cardiovascular morbidity, also at air pollution concentrations below normal health guidelines (Barnett et al., 2006; Hoek et al., 2001). Exposure to the same pollutants was found for to be associated with increasing cardiovascular mortality (Beelen et al., 2008; Bhaskaran et al., 2009; Brook, 2007; Brunekreef et al., 2009; Hoek et al., 2001; Maitre et al., 2006).

In Santiago de Chile, a significant increase of daily cardiovascular hospital admissions due to PM10 exposure was found for adults, 0.9% (0.35%–1.44%) and elderly 1.2% (0.70%–1.63%). In general, the associations were more significant for PM10 than for PM2.5 (Vera et al., 2007) and not significant for ozone (Vera and Cifuentes, 2008).

2. Material and methods

2.1. Study area and period

In the city of Santiago live around 5.39 Mio inhabitants (census 2002, Región Metropolitana). Santiago (latitude 33°28′ S, longitude 70° 45′ W; 600 m above sea level) is situated in a valley between the Andes and Cordillera de la Costa mountain ranges and is separated by 100 km from the coast of the Pacific Ocean (Gramsch et al., 2006). Owing to this unique geographic location, ventilation and dispersion of air pollution are highly restricted. During the summer months, central Chile is generally under the influence of the subtropical anticyclone in the south-eastern Pacific, resulting in clear sky and high temperatures in Santiago (Schmitz, 2005). Under such conditions, the formation of O_3 through the photochemical oxidation of CO and volatile organic compounds (VOC) in the presence of high concentrations of nitrogen oxides (NOx, NO, NO_2) is favored. Despite of moderate yearly means, yearly and daily variations of exposure concentrations are high which results in rather high numbers of days with exceedances of the Chilean National Ambient Air Quality Standard (NAAQS) mean of 80 ppb maximum hourly and the NAAQS average of 61 ppb maximum over 8 h (Bell et al., 2008; Seguel et al., 2012). This limit was also often exceeded during the study period (Supplementary data, Fig. S1).

The degree of urbanization in Chile amounts to 88.7%. One third of the total population of Chile lives in the capital.

2.2. Health data

For the evaluation of health effects of air pollutants we used data of the Ministerio de Salud de Chile. The data were kindly provided by the Departamento de Estadísticas e Información de Salud (DEIS). The data included all cases of hospital admissions (in total 75,303) which are registered by the Fondo Nacional de Salud de Chile (FONASA) and the Instituciones de Salud Previsional (ISAPREs). We summarized the case numbers per day according to their ICD-10 codes. This study used the case numbers of diseases of the circulatory system: I00–I99 (all types of diseases of the circulatory system), I05–I09, I20–I25, I26–I28, and I30–I52 (heart diseases), I20–I25 (ischemic heart diseases), and I30–I52 (other forms of heart diseases).

2.3. Air pollution data

The exposure of Santiago's inhabitants was estimated using the averages of the pollutant concentrations measured by seven of eight monitoring stations of the atmospheric pollution monitoring Network at Santiago de Chile (Fig. 1). Measurements of all stations included PM10, PM2.5, NO_2, CO, and O_3. Only the Las Condes station was excluded. This station is not characteristic for the exposure of the population of Santiago. Due to the location of the station Las Condes at a higher altitude and within a region with less emission sources the average concentrations of primary pollutants like NO, PM and VOCs are much lower compared to the other stations which are located closer to the city center. On the other hand the more remote located station is measuring higher concentrations of ozone due to higher photochemistry activity. In Las Condes live only around 4.6% of the inhabitants of the city. These population may have been less exposed e.g. by PM at least when they were not working or staying in other parts of the city. Therefore, this station has to be excluded from the averaging. An average using all other monitoring stations is more suitable for the characterization of the typical exposure of at least 95% of the urban population. Seasonal monitors were not included. The data availability of the measurements varied from close to 90% for ozone until about 95% for particulate matter (PM).

2.4. Meteorological data

Meteorological data (wind speed, direction, temperature, humidity) were provided by a local monitoring network (Suppan et al., 2012) and weather underground (www.wunderground.com).

2.5. Statistical analysis

The intention of the study was to quantify relationships between daily variations of the concentrations of common airborne pollutants and daily incidences of cardiovascular disease groups measured by hospital admissions in Santiago de Chile. There exist a variety of methods in environmental epidemiology to analyze the influence of pollutants on health. It has been shown that case-crossover and time series methods produce similar results (Basu et al., 2005; Lu and Zeger, 2007; Tong et al., 2012). We applied case-crossover analysis (CCO) with a daily resolution.

The data contain seasonal cycles in health, air pollution, and meteorological data. We were not interested in long-term but in the short-term effects. Therefore, the seasonal cycles have to be controlled for as they might introduce a significant effect. A time stratified CCO was applied for studying the effects of different air pollutants on cardiovascular morbidity. The CCO was presented by Maclure (1991) to investigate transient effects on the risk of acute events while controlling for seasonality and other short-term influences. Since its introduction, the CCO has been applied in many studies about the short-term effects of air