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Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain

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ABSTRACT

Proximity to road traffic involves higher health risks because of atmospheric pollutants. In addition to outdoor air, indoor air quality contributes to overall exposure. In the framework of the BREATHE study, indoor and outdoor air pollution was assessed in 39 schools in Barcelona. The study quantifies indoor and outdoor air quality during school hours of the BREATHE schools. High levels of fine particles ($PM_{2.5}$), nitrogen dioxide (NO_2), equivalent black carbon (EBC), ultrafine particle (UFP) number concentration and road traffic related trace metals were detected in school playgrounds and indoor environments. $PM_{2.5}$ almost doubled (factor of 1.7) the usual urban background (UB) levels reported for Barcelona owing to high school-sourced $PM_{2.5}$ contributions: [1] an indoor-generated source characterised mainly by organic carbon (OC) from organic textile fibres, cooking and other organic emissions, and by calcium and strontium (chalk dust) and; [2] mineral elements from sand-filled playgrounds, detected both indoors and outdoors. The levels of mineral elements are unusually high in $PM_{2.5}$ because of the breakdown of mineral particles during playground activities. Moreover, anthropogenic PM components (such as OC and arsenic) are dry/wet deposited in this mineral matter. Therefore, $PM_{2.5}$ cannot be considered a good tracer of traffic emissions in schools despite being influenced by them. On the other hand, outdoor NO_2, EBC, UFP, and antimony appear to be good indicators of traffic emissions. The concentrations of NO_2 are 1.2 times higher at schools than UB, suggesting the proximity of some schools to road traffic. Indoor levels of these traffic-sourced pollutants are very similar to those detected outdoors, indicating easy penetration of atmospheric pollutants. Spatial variation shows higher levels of EBC, NO_2, UFP and, partially, $PM_{2.5}$ in schools in the centre than in the outskirts of Barcelona, highlighting the influence of traffic emissions. Mean child exposure to pollutants in schools in Barcelona attains intermediate levels between UB and traffic stations.

1. Introduction

Some of the health effects of exposure to air pollution, such as the impact on the respiratory and cardiovascular systems, have been extensively studied. Although it is well-known that exposure to air pollutants leads to an increase in mortality and morbidity rates of the population (e.g. Baccarelli et al., 2008; Künzli et al., 2000, 2004; Pope et al., 2002; WHO, 2005), few studies have focused on the role of air pollution on brain development. Evidence obtained from experimental studies in animals suggests that outdoor air pollution may play a major role in the inflammation of the central nervous system during sensitive periods (such as childhood) and consequently in behaviour and school performance (Block et al., 2012). A growing body of research, albeit limited, from epidemiological studies indicates that exposure to air pollution may be associated with an increased risk of neurodevelopmental disorders and cognitive impairments (Guxens and Sunyer, 2012).

Many epidemiological studies relate $PM_{2.5}$ (particles with and aerodynamic diameter <2.5 μm) to negative health outcomes (Dockery et al., 1993; Jerrett et al., 2005; Krewski et al., 2009; Laden et al., 2006; Lepeule et al., 2012; Pope et al., 2002). However, owing to the small size of ultrafine particles (UFP, particles <100 nm) that can translocate

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Abbreviations: UB, urban background; UB-PR, urban background reference station of Palau Reial in Barcelona; SC, sampling campaign; UFP, ultrafine particles; LDSA, lung-deposited surface area; EC, elemental carbon; BC, black carbon; EBC, equivalent black carbon; OC, organic carbon; OM, organic matter.

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from the lung to the blood circulatory system or be taken up directly into the brain through the olfactory epithelium (Chen et al., 2006; Nemmar, 2002; Oberdörster et al., 2004), UFP arise as a potential $PM_{2.5}$ constituent to have large health effects (Knol et al., 2009) even though the evidence is still limited (Rückerl et al., 2011). The negative health effects of the proximity to road traffic might be more related to the exposure to UFP, black carbon (BC) and total PM counts since Zhu et al. (2002) found that they decreased rapidly in the first 150 m away from the traffic line and then levelled off, whereas $PM_{2.5}$ was found to be elevated only moderately.

Mediterranean cities are characterised by high densities of population and motor vehicles: there are about 5800 $cars \cdot km^{-2}$ in Barcelona and about 4500 $cars \cdot km^{-2}$ in Turin and Naples whereas these densities fall to 1000–1500 $cars \cdot km^{-2}$ in northern and central European cities such as Budapest, Amsterdam or Berlin (Ajuntament de Barcelona, 2013). Hence, people living in more densely populated cities are closer to traffic and are more exposed to vehicle exhaust and non-exhaust emissions. In fact, recent studies have shown that cities in southern Europe have higher levels of $PM_{2.5-10}$ than those in northern and central Europe owing to the high vehicle density and drier weather (Eeftens et al., 2012; Querol et al., 2004a). The contribution from road dust (non-exhaust emissions from pavement, tyre and brake wear and resuspension of the material deposited on the road) to PM levels is also higher in Mediterranean cities (Pant and Harrison, 2013). Some vehicle wear abrasion particles have a mode below $PM_{2.5}$ and another mode above this diameter that would only be present in $PM_{2.5-10}$; e.g. the mass modes of Fe, Cu, Ba and Sb are between 1.2 and 7.2 μm aerodynamic diameter (Gietl et al., 2010); a bimodal structure for Sb has been determined with a mode at 3.6–5.2 μm from brake wear and tear (Ijima et al., 2009).

There is increasing evidence that indoor air quality exposure is also responsible for a rise in mortality and morbidity (Sundell, 2004). However, little is known about air quality in indoor environments, where children spend most of the day (approximately 90%; Buonanno et al., 2012; US-EPA, 2008). Moreover, children constitute a particularly vulnerable population because of their physiological and behavioural characteristics. They have higher ventilation rates and higher levels of physical activity (Trasande and Thurston, 2005) with the result that they are more exposed to air pollutants than adults. Children spend a large part of their time at school both indoors and outdoors. In Spain, the school year lasts about 180 days and an average of 25 h per week at primary level (INCA, 2013). Although the association between air pollution exposure at schools and the impact on health has been the subject of more than 70 epidemiological publications (see Mejía et al., 2011), neurodevelopment has, by contrast, been poorly documented. Newman et al. (2013) found an association between elemental carbon (EC) from traffic and higher hyperactivity scores in children. In a study of one school in a highly polluted area and in another school in an area of low pollution in Quanzhou, China, Wang et al. (2009) found that neuropsychological functions, such as attention, were impaired in the former school with respect to the latter. The mechanisms responsible for the initiation of neuroinflammation in response to air pollution are poorly understood and may be exposure-specific (Block et al., 2012).

At schools, indoor concentrations of particulate matter have been shown to be highly correlated with outdoor levels, suggesting that indoor particles are largely of outdoor origin (Raysoni et al., 2011). However, this indoor penetration of outdoor particles depends not only on the physical barriers of the building and ventilation (natural or mechanical), but also on particle physico-chemical properties (Viana et al., 2011) and size (Tippayawong et al., 2009; Zhu et al., 2002).

It may well be that epidemiological studies are considerably influenced by the methods employed for the collection of air quality data, such as the instrumentation used, the sampling location, the pollutants and parameters monitored and the sampling period (Mejía et al., 2011) since the methodology selected could result in over/under-estimation of exposure. Mejía et al. (2011) have also highlighted the importance of the spatial unit of analysis. In epidemiological studies the nearest air quality monitoring station is generally used to represent the air quality in schools (sometimes using raw data from the station and other times estimating levels at schools). However, measuring in-situ at schools yields more accurate information about the exposure although Buonanno et al. (2013), Janssen et al. (2001) and Salimi et al. (2013) have reported some spatial variation in the concentration of some air pollutants within the school. Therefore, personal exposure monitoring is the most accurate methodology to assess the exposure to air pollutants (Buonanno et al., 2012).

The BREATHE (BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn) ERC Advanced Grant project seeks to determine whether traffic-related air pollutants have an adverse effect on neuropsychological development, exacerbating cognitive and neurobehavioral disorders. The aim of the present study is to characterise indoor and outdoor air quality and its variability, especially the parameters that are most influenced by traffic emissions at the schools participating in the BREATHE study.

2. Materials and methods

2.1. Study area

The study was carried out in the city of Barcelona (Spain; 15,993 $inhabitants \cdot km^{-2}$) and in the adjacent municipality of Sant Cugat del Vallès (1761 $inhabitants \cdot km^{-2}$; IDESCAT, 2012; Fig. 1). Both cities are located in the NE of the Iberian Peninsula and have a Mediterranean climate. Barcelona has one of the highest vehicle densities in Europe (Ajuntament de Barcelona, 2012). The urban traffic fleet is characterised by a large number of cars (60.6%, of which, since 2003, more than 60% of the new car registrations are diesel; DGT, 2011); motorcycles (30.2%), heavy duty vehicles (2.9%). Furthermore, Barcelona is one of the most important ports in the Mediterranean, and receives the highest number of cruise ships in Spain. This constitutes an additional source of atmospheric pollutants that are very often transported across the city by the sea breeze during the day. Owing to the topography of the area, the transport and dispersion of atmospheric pollutants within Barcelona are largely controlled by fluctuating coastal winds which blow in from the sea during the day (diurnal breeze), and, to a lesser extent, by winds from the land at night (night breeze, Jorba et al., 2013). In the city centre, the predominance of narrow streets (street canyons) and a dearth of green areas hinder the dispersion of pollutants. Moreover, the city is not infrequently affected by North African air mass transport (NAF), which contributes significantly to mineral $PM_{2.5}$.

On the other hand, Sant Cugat lies in the Vallès Depression away from the coast and is bounded by the Littoral mountain range to the southeast and by the Pre-Littoral mountain range to the northwest. Although these ranges shield the city from coastal pollutant intrusions (Fig. 1), the Llobregat Valley offers an atmospheric corridor into the Vallès Depression for air pollutants carried from the urban and industrial zones that surround the river. Once in this Depression, the pollutants accumulate due to the poor dispersion conditions.

2.2. Monitoring sites: schools and reference urban background station

Two sampling campaigns were carried out in 36 schools in Barcelona and 3 in Sant Cugat, from 27 January until 22 June 2012 (SC1; sampling campaign 1) and from 14 September 2012 until 22 February 2013 (SC2; sampling campaign 2). Traffic intensity and typology of the fleet around the schools is shown in Table S1. The sampling was performed simultaneously indoors (in a classroom with pupils) and outdoors (in the playground) at two schools per week; of this pair of schools, one was located in an urban background (UB) area, whereas the other one was situated near traffic. Indoor devices were placed where possible next to the wall opposite the blackboard (to avoid direct exposure to chalk or board marker emissions) and away from the windows (to avoid direct