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How to protect school children from the neurodevelopmental harms of air pollution by interventions in the school environment in the urban context

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ABSTRACT

Recently, there has been a flurry of publications assessing the effect of air pollution on neurodevelopment. Here we present a summary of the results obtained within the BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn (BREATHE) Project, which aimed to evaluate the effects of the exposure to traffic related air pollutants in schoolchildren in Barcelona. To this end, we comprehensively characterised air quality in 39 urban schools from Barcelona and identified the main determinants of children's increased exposure. We propose a series of measures to be implemented to improve air quality in schools within the urban context and, consequently, minimise the negative effects on children's neurodevelopment that we found to be associated with the exposure to air pollution. We also aimed to list some of the actions pushed by governments and the society (including school managers, parents, and children) that have been taking place around Europe for promoting better high quality in the school and its surroundings.

1. Introduction

Over 80% of world's population lives in urban areas that have higher levels of air pollution than the guidelines set by the WHO (2006). Particulate air pollution is the main environmental contributor to the global burden of disease and is one of the top preventable causes of disease over time (Cohen et al., 2017). Air pollution effects on the respiratory (such as asthma and reduced lung function) and cardiovascular system are well established but, because of the inadequacy of the available evidence, the potential effects of air pollution on brain development (and cognitive decline) have not been considered to date when estimating the burden associated with air pollution (Cohen et al., 2017). Pioneering studies on brain tissue from autopsies in dogs and children living in highly polluted areas of Mexico City showed inflammation in several brain areas (Calderón-Garcidueñas et al., 2008) and this work led to a long series of experiments in mice exposed to fine, ultrafine, and diesel particles (Costa et al., 2014). In mice, the central nervous system could be a direct or indirect target (via the olfactory or lung pathway, respectively) of particles that elicit a neuroinflammatory response in various brain regions. In humans, exposure to air pollution in utero is associated with increased risk of neurodevelopmental delay and autism (Lam et al., 2016).

Children are particularly vulnerable to environmental exposures since they are still under development. Moreover, due to their physiological (e.g. high breathing rates) and behavioural distinctions (e.g. high physical activity), children may receive higher doses of air pollutants than adults. As they spend long time in a shared location such as the school, it is important to ensure a good air quality in this environment for the benefit of the children and public health. Schools are a setting where children are aimed to expand their knowledge and manage behavioural responses, among other skills. Therefore, a proper characterisation of air pollutants in the schools and their associated health effects on cognition are needed to identify and target preventive actions to minimise the impact of air pollution.

BREATHE (BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn) is the largest epidemiological study in the general population assessing whether exposure of children to traffic related air pollutants (TRAPs) in schools adversely affects cognitive development (Sunyer et al., 2015) of urban children. The key strengths of BREATHE were the direct assessment of exposure in school classrooms and the school playgrounds, the study of cognitive function trajectories using repeated exams and the inclusion of neuroimaging. Here, we briefly

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Table 1
List of all BREATHE publications summarised in this article a by main topic.

Topic	References	Main findings
Air quality in school: levels, sources, pollutant infiltration, and greenness	Amato et al. (2014)	Identification of 7 outdoor and 2 children-activity-related $PM_{2.5}$ sources at schools.
	Dadvand et al. (2015b)	A reduction of indoor and outdoor air pollution was associated with greenness within and around schools.
	Minguillón et al. (2015)	The sands from playgrounds are fine enough to be resuspended and increase PM concentrations.
	Moreno et al. (2014)	Air quality in schools has notable spatial and temporal variations. High concentrations of traffic-carbon and metal PM into the classroom.
	Reche et al. (2015)	Indoor and outdoor BC levels depend on the distance to traffic.
	Reche et al. (2014)	Schools near traffic showed 40% higher indoor and outdoor UFP concentrations. High indoor UFP contributions from cooking, cleaning, and surface chemistry reactions mediated by O_3.
	Rivas et al. (2015)	High infiltration of air pollutants, with maximum infiltration observed for BC and Cd.
	Rivas et al. (2014)	School concentrations of BC, NO_2, UFP and, partially, $PM_{2.5}$ where the influenced by traffic emissions. Intermediate levels between UB and traffic stations were observed in schools.
Children's personal exposure	Nieuwenhuijsen et al. (2015)	The correlation between modelled (LUR) and measured personal black carbon levels was generally good, except for commuting times.
	Rivas et al. (2016)	School contributes to 37% of children's daily dose. Commuting periods have the highest dose:time intensity.
Aerosol instrumentation	Viana et al. (2015)	Good performance of three portable monitors for BC, UFP, and PM mass concentrations when compared with reference stationary monitors.
Air pollution and cognitive development	Alvarez-Pedrerol et al. (2017)	Exposure to $PM_{2.5}$ and BC during commuting by foot was associated with a reduced growth of working memory
	Basagaña et al. (2016)	From 9 different $PM_{2.5}$ sources, traffic was the only one associated with a reduction in cognitive development.
	Forns et al. (2016)	TRAPs at school were associated with increased behavioural problems and noise with more ADHD symptoms.
	Sunyer et al. (2015)	Children attending schools with higher TRAPs had a reduced improvement in cognitive development.
	Sunyer et al. (2017)	Short-term exposures to TRAPs were negatively associated with attention.
Gene-environment interactions	Alemany et al. (2016)	Involvement of the *PID1* gene, mTOR signalling and Alzheimer disease-amyloid secretase pathways in attention functions.
	Alemany et al. (2018)	For *APOE ε4* allele carriers, TRAPs were associated with higher behaviour problems and smaller reductions in inattentiveness, while no or weak associations were observed in *APOE ε4* noncarriers.
Air pollution and brain (MRI)	Mortamais et al. (2017)	Exposure to PAHs is associated with reduction in the caudate nucleus volume. No significant associations between PAH and ADHD symptoms.
	Pujol et al. (2016)	TRAPs were associated with brain changes of a functional nature, with no evident effect on brain anatomy, structure, or membrane metabolites.
Greenness and cognitive development	Dadvand et al. (2015a)	There was a beneficial association between exposure to green spaces in school and cognitive development, partly mediated by a reduction in exposure to air pollution.
Greenness and brain (MRI)	Dadvand et al. (2018)	Lifelong exposure to greenness was positively associated with grey and white matter volume in different regions of the brain.

MRI: Magnetic Resonance Imaging; BC: Black Carbon; UFP: ultrafine particles; PM: Particulate Matter; LUR: Land use Regression Models; TRAPs: Traffic-related air pollutants.

summarise the findings of the subprojects across the BREATHE Project (listed in Table 1) with the aim to discuss potential interventions at urban schools to lessen the negative effects of air pollution on children's neurodevelopment.

2. Data collected

Participants were recruited through cluster sampling by first selecting 39 schools in Barcelona (Catalonia, Spain) and then inviting all students without special needs in grades 2 through 4 (7–10 years of age) to participate (Sunyer et al., 2015). Most of the participants lived in Barcelona city, with some of them residing in suburban areas from the Barcelona Metropolitan Area. Participating children (n = 2897) from the 39 high and low TRAPs schools, paired by socio-economic status, were tested via a series of four computerized tests from January 2012 to March 2013 to evaluate working memory development, executive attention, impulsivity, and selective attention (Sunyer et al., 2015). Behavioural problems (Strengths and Difficulties Questionnaire) were reported by parents. Teachers reported Attention Deficit and Hyperactivity Disorder (ADHD) symptoms of each child using the ADHD Criteria of Diagnostic and Statistical Manual of Mental Disorders, fourth edition (ADHD-DSM-IV) list. From teacher ratings, we classified the children as having ADHD if 6 or more symptoms were present (López-Vicente et al., 2016). MRI (T2, flair, spectroscopy, and DTI) and fMRI (resting, visual and audition stimuli) were conducted in 265 children (Pujol et al., 2016). To assess gene-environment interaction, DNA samples were obtained from saliva samples from 2492 children, from which a subset of 1778 was selected for Genome Wide Association study (GWAs) (Alemany et al., 2016). A similar protocol to assess working memory and attention was applied to the 9-year follow-up of the INMA -Infancia y Medio Ambiente (Environment and Childhood) - birth cohort children (Gascon et al., 2017) to replicate the results in the near future.

Air pollution (nitrogen dioxide (NO_2; Gradko dosimeters), ultrafine particle number (UFP; DiSCmini, Matter Aerosol), Black Carbon (BC; MicroAethAE51, Aethlabs), and particulate matter (PM) ≤ 0.25 μm (quasi-ultrafines), 0.25 to 2.5 μm (accumulation mode), 2.5 to 10 μm (coarse mode; all the previous fractions with a Sioutas Personal Cascade Impactor), ≤ 2.5 μm ($PM_{2.5}$; with a MCV high volume sampler)) was measured during two one-week campaigns simultaneously inside the classroom and on the playground in each school pair during 2012 (Rivas et al., 2014). A total of 1092 PM filters were collected and more than 50 inorganic and organic compounds and elements were analysed (including organic carbon (OC), elemental carbon (EC), Al_2O_3, Ca, Sr, Fe, Mg, Cu, Sb, Sn, As, Co, Pb, Cr, and Polycyclic Aromatic Hydrocarbons (PAHs)). The same pollutants were also monitored in a reference urban background station in Barcelona (UB-PR). Note that for UFP, instruments with different size range were used and therefore the