Science of the Total Environment 523 (2015) 59–63

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The association between greenness and traffic-related air pollution at schools

Payam Dadvand [a,b,c,*], Ioar Rivas [a,b,c,d], Xavier Basagaña [a,b,c], Mar Alvarez-Pedrerol [a,b,c], Jason Su [e], Montserrat De Castro Pascual [a,b,c], Fulvio Amato [d], Michael Jerret [e], Xavier Querol [d], Jordi Sunyer [a,b,c], Mark J. Nieuwenhuijsen [a,b,c]

[a] *Centre for Research in Environmental Epidemiology (CREAL), C/Dr. Aiguader 88, 08003 Barcelona, Spain*
[b] *CIBER Epidemiología y Salud Pública (CIBERESP), C/Monforte de Lemos 3-5, 28029 Madrid, Spain*
[c] *Universitat Pompeu Fabra (UPF), Plaça de la Mercè, 08002 Barcelona, Spain*
[d] *Institute of Environmental Assessment and Water Research (IDAEA), Spanish National Research Council (CSIC), C/Jordi Girona 18-26, 08034 Barcelona, Spain*
[e] *Environmental Health Sciences, School of Public Health, University of California, Berkeley, 50 University Hall, Berkeley, CA, 94720-7360, USA*

HIGHLIGHTS

- Reduced indoor and outdoor air pollution associated with greenness within schools.
- Reduced indoor and outdoor air pollution associated with greenness around schools.
- Reduction in indoor air pollution was mediated by reduction in outdoor levels.

ARTICLE INFO

Article history:
Received 27 October 2014
Received in revised form 13 March 2015
Accepted 23 March 2015
Available online 7 April 2015

Editor: Lidia Morawska

Keywords:
Air pollution
Green space
Child health
NDVI
School
Vegetation

ABSTRACT

Greenness has been reported to improve mental and physical health. Reduction in exposure to air pollution has been suggested to underlie the health benefits of greenness; however, the available evidence on the mitigating effect of greenness on air pollution remains limited and inconsistent. We investigated the association between greenness within and surrounding school boundaries and monitored indoor and outdoor levels of traffic-related air pollutants (TRAPs) including NO_2, ultrafine particles, black carbon, and traffic-related $PM_{2.5}$ at 39 schools across Barcelona, Spain, in 2012. TRAP levels at schools were measured twice during two one-week campaigns separated by 6 months. Greenness within and surrounding school boundaries was measured as the average of satellite-derived normalized difference vegetation index (NDVI) within boundaries of school and a 50 m buffer around the school, respectively. Mixed effects models were used to quantify the associations between school greenness and TRAP levels, adjusted for relevant covariates. Higher greenness within and surrounding school boundaries was consistently associated with lower indoor and outdoor TRAP levels. Reduction in indoor TRAP levels was partly mediated by the reduction in outdoor TRAP levels. We also observed some suggestions for stronger associations between school surrounding greenness and outdoor TRAP levels for schools with higher number of trees around them. Our observed reduction of TRAP levels at schools associated with school greenness can be of public importance, considering the burden of health effects of exposure to TRAPs in schoolchildren.

1. Introduction

Contact with greenness has been shown to improve perceived and objective physical and mental health (Bowler et al., 2010; Lee and Maheswaran, 2011). Although the underlying mechanisms of health benefits of greenness are not well understood, reduction in exposure to air pollution has been suggested as one explanation (Bowler et al., 2010). The available evidence, however, on the mitigating effect of greenness on air pollution with regard to human exposure remains limited and inconsistent (Dadvand et al., 2012a, Hagler et al., 2012).

Abbreviations: BC, black carbon; BREATHE, BRain dEvelopment and Air polluTion ultrafine particles in scHool children; CI, confidence intervals; IQR, interquartile range; NDVI, normalized difference vegetation index; LDSA, lung-deposited surface area; LUR, land use regression; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5 µm; RC, regression coefficient; TRAP, traffic-related air pollutant; UFP, ultrafine particles; VOC, volatile organic compound.

* Corresponding author at: CREAL, Doctor Aiguader, 88, 08003 Barcelona, Spain.
E-mail address: pdadvand@creal.cat (P. Dadvand).

http://dx.doi.org/10.1016/j.scitotenv.2015.03.103

Children spend a large proportion of their time at school when traffic pollution peaks during the day. Many schools are located in proximity to busy roads, increasing the level of traffic-related air pollutants (TRAPs) at the schools. Exposure to TRAPs at school has been associated with a range of adverse health impacts including respiratory conditions (McConnell et al., 2010) and impaired neurodevelopment (Shu et al., 2009) in schoolchildren, which are accompanied with a considerable personal and societal burden.

This study aimed to investigate the association between school greenness (separately for greenness within boundaries of schools and greenness surrounding schools) and TRAP levels at schools (separately for indoor and outdoor levels).

2. Methods

We undertook this study in Barcelona, Spain, a port city situated on the Northeastern part of the Iberian Peninsula. Air pollution concentrations in Barcelona are among the highest in Europe. It has a Mediterranean climate characterized by hot and dry summers, mild winters, and maximum precipitation and vegetation during autumn and spring. This study was conducted in the context of the BRain dEvelopment and Air polluTion ultrafine particles in scHool childrEn (BREATHE) project (Amoly et al., 2014).

2.1. Schools

Of the 416 schools in Barcelona, 37 schools were initially selected to obtain maximum contrast in TRAP levels (i.e., NO_2); 36 (18 pairs) agreed to participate and were included in the study. Low and high NO_2 schools were paired by neighborhood socioeconomic status and type of school (public vs. private). Additionally, three more schools from an adjacent municipality, Sant Cugat del Vallès, were included in BREATHE (39 schools in total). Participating schools were similar to the remaining schools in Barcelona in terms of the socioeconomic vulnerability index (0.46 versus 0.50, $p = 0.57$) and NO_2 levels (51.5 versus 50.9 $\mu g/m^3$, $p = 0.72$).

2.2. Air pollution measurements

We selected NO_2, black carbon (BC), and ultrafine particles (UFPs) given their relation to road traffic emissions in Barcelona (Amato et al., 2014; Reche et al., 2014; Rivas et al., 2014). For UFP (in the range of 10–700 nm), we separately analyzed number concentration and lung-deposited surface area (UFP-LDSA). Because of the strong correlation between these two variables (Spearman's correlation coefficient of 0.9) and consistency of the findings for them, for this short communication we only present the results for UFP-LDSA, which is likely to be more biologically relevant.

TRAP levels at each pair of schools were simultaneously measured twice during one-week campaigns separated by 6 months, once in the warm and once in the cold seasons of the year 2012. The sampling was simultaneously performed indoors (in a classroom) and outdoors (in the playground). Air samples were collected at a height between 0.7 and 1.5 m above floor level, which is the height at which the pupils aged 7–9 would usually inhale. Real-time BC and UFP concentrations were measured using MicroAeth AE51 (AethLabs, USA) and DiSCmini (Matter Aerosol, Switzerland) monitors, respectively, during the 8-hour school time when children were at school. The DiSCmini device is based on unipolar charging of the particle, followed by their detection in two electrometer stages. The charge is size-dependent, and, the LDSA is proportional to the diffusion charger signal. This method has been detailed in (Fierz et al., 2011). Weekly averaged NO_2 concentrations were measured by Gradko Environmental passive dosimeters. Detailed description of sampling methodology has been previously published (Amato et al., 2014; Reche et al., 2014; Rivas et al., 2014).

Furthermore, based on chemical analysis of the 8-hour a day particulate matter with aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$) samples collected by high volume (30 m^3/h) MCV samplers, we estimated the contribution of traffic to $PM_{2.5}$ concentrations using a Positive Matrix Factorization model as described elsewhere (Amato et al., 2014). This traffic-related $PM_{2.5}$ concentration (hereafter referred to as $PM_{2.5}$-traffic) comprised organic particles from motor exhaust, elemental carbon as well as metals from brake wear (Cu, Sb, Sn and Fe). We used $PM_{2.5}$-traffic as another indicator of TRAP at schools.

2.3. School greenness

We assessed the greenness within and around the school boundaries by means of normalized difference vegetation index (NDVI) (Weier and Herring, 2011) derived from RapidEye images at 5 m × 5 m resolution. The RapidEye imagery is acquired from a constellation of five satellites 630 km above grant in sun-synchronous orbits. Each satellite has a multi-spectral push broom imager sensor that collects data in blue, green, red, red edge and near-infrared. NDVI is an indicator of greenness based on land surface reflectance of visible (red) and near-infrared parts of spectrum (Weier and Herring, 2011). It ranges between -1 and 1 with higher numbers indicating more greenness. We generated our NDVI map using the image obtained on July 23rd, 2012. This image was radiometrically corrected and presented in pixel values (digital numbers). These digital numbers were converted to the Top of Atmosphere radiance before the NDVI was estimated.

To assess greenness within school premises we first digitized the school boundaries and then averaged NDVI values within those boundaries. To assess greenness surrounding schools we averaged NDVI values in a 50 m buffer around the school boundaries.

2.4. Statistical analysis

For each exposure–outcome pair, we developed mixed effects models with school as random effect to account for the repetitive measurements for each school. We used weekly indoor and outdoor levels of each TRAP (one at a time) measured during each campaign as the outcome and greenness within and surrounding school boundaries (one at a time) as fixed-effect predictors. Given that different school pairs were monitored in different weeks during each campaign period, we adjusted the analyses of each TRAP for the weekly average level of that TRAP (during the corresponding sampling week for each school pair) measured by a background monitoring station in Barcelona to remove temporal fluctuation in background TRAP levels from our analyses (Rivas et al., 2014). We further adjusted the models of indoor TRAPs for meteorological indicators (average temperature and humidity and total precipitation during the sampling week), monitor placement (ground floor: yes/no) and orientation (facing inward/towards street/towards playground), and school characteristics including building age and ventilation as fixed-effect predictors. Air-conditioning systems or heaters were not available in any of the classrooms and natural ventilation through windows and doors was the only type of ventilation in classrooms. Teachers were asked to fill in a logbook describing the frequency with which the windows and doors were opened during the sampling period.

In addition to background TRAP levels, models of outdoor TRAPs were adjusted for meteorological indicators and monitor placement as fixed-effect predictors. To address the impact of traffic around the school, we further adjusted the analyses of outdoor TRAPs for those traffic indicators that showed to be the best predictors for each TRAP in land use regression (LUR) models developed for Barcelona (Beelen et al., 2013; Eeftens et al., 2012). Accordingly, the analyses for outdoor NO_2 levels were further adjusted for squared distance to the nearest major road, product of traffic intensity on the nearest road and inverse of distance to the nearest road, and total length of roads (all types) in a 1000 m buffer around the school. For $PM_{2.5}$-traffic and UFP there was