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Impact of commuting exposure to traffic-related air pollution on cognitive development in children walking to school☆

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ABSTRACT

A few studies have found associations between the exposure to traffic-related air pollution at school and/or home and cognitive development. The impact on cognitive development of the exposure to air pollutants during commuting has not been explored. We aimed to assess the role of the exposure to traffic-related air pollutants during walking commute to school on cognitive development of children. We performed a longitudinal study of children (n = 1,234, aged 7–10 y) from 39 schools in Barcelona (Catalonia, Spain) who commuted by foot to school. Children were tested four times during a 12-month follow-up to characterize their developmental trajectories of working memory (*d'* of the three-back numbers test) and inattentiveness (hit reaction time standard error of the Attention Network Test). Average particulate matter ≤2.5 μm ($PM_{2.5}$), Black Carbon (BC) and NO_2 concentrations were estimated using Land Use Regression for the shortest walking route to school. Differences in cognitive growth were evaluated by linear mixed effects models with age-by-pollutant interaction terms. Exposure to $PM_{2.5}$ and BC from the commutes by foot was associated with a reduction in the growth of working memory (an interquartile range increase in $PM_{2.5}$ and BC concentrations decreased the annual growth of working memory by 5.4 (95% CI [-10.2, -0.6]) and 4.6 (95% CI [-9.0, -0.1]) points, respectively). The findings for NO_2 were not conclusive and none of the pollutants were associated with inattentiveness. Efforts should be made to implement pedestrian school pathways through low traffic streets in order to increase security and minimize children's exposure to air pollutants.

1. Introduction

Good air quality is required for human health and wellbeing, however more than 80% of people residing in urban areas are exposed to air pollutant concentrations that are above the World Health Organization (WHO) standards (WHO, 2016). There is increasing evidence of the adverse effects of exposure to air pollution on children's health (WHO, 2005), and air pollution has been recently considered as a suspected cause of developmental neurotoxicity (Block et al., 2012). In previous research within the framework of the BREATHE (Brain Development and Air Pollution Ultrafine Particles in School Children) project (http://www.creal.cat/projectebreathe), long-term exposures during school time to traffic-related air pollutants (TRAPs) were associated with a reduction in cognitive development (Basagaña et al., 2016; Sunyer et al., 2015). Studies evaluating the impact of air pollution on cognitive function in children are limited and mainly focused on the exposure at home or school (Suades-González et al., 2015).

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Nonetheless, no studies have assessed the impact on cognitive development of the exposure to air pollutants during commuting time.

Children are highly exposed to TRAPs during commuting from home to school which often coincides with traffic pollution peaks (Nieuwenhuijsen et al., 2015). Some studies have found that although time spent during commuting might be short, the commuters receive a high proportion of their daily TRAP dose (De Nazelle et al., 2013; Dons et al., 2012) including children commuting to school (Buonanno et al., 2012; Nieuwenhuijsen et al., 2015; Rivas et al., 2016). In particular, from a BREATHE subpopulation of 45 children, Rivas et al. (2016) showed that while children on average spent 6% of the daytime in commuting, it accounted for about 20% of the daily integrated dose of Black Carbon (BC). Moreover, toxicological and experimental studies have evidenced that these short exposure to extremely high pollutant concentration may have disproportionate health impacts (Michaels and Kleinman, 2000). These health effects are expected to be especially important in children, who breathe in a higher normalized dose of airborne particles than adults (Buonanno et al., 2011).

The specific health effects from the exposure to air pollutants during commuting remain largely unexplored. Liu et al. (2015) observed associations between the exposure to $PM_{2.5}$ and heart rate variability in young healthy subjects. $PM_{2.5}$ concentrations were dependent on the commuting mode, with the highest concentrations and cardiovascular effects observed in the walking mode. The time spent in vehicles during commuting (cars, public transportation, motorcycles or bicycles) has also been associated with an increase in the risk of myocardial infarction in adults (Peters et al., 2004).

Some cognitive functions, such as working memory or attention, develop substantially during childhood and adolescence (Tamnes et al., 2013). These capacities are shown to be critical for academic achievement (Shelton et al., 2010). This work aimed to study the effects of long-term exposure to TRAPs during home to school commuting by foot on cognitive development in primary schoolchildren.

2. Methods

2.1. Participants

A total of 2897 children in grades 2 to 4 (7–10 y of age) attending 39 different schools in Barcelona (Catalonia, Spain) agreed to participate in the ERC-Advanced Grant (FP7) BREATHE Project. From the total number of BREATHE participants, we included in this study 1234 children reporting walking as the unique mode of transport to commute to school and having complete data. All parents or guardians signed the informed consent form approved by the Clinical Research Ethical Committee (No. 2010/41221/I) of the Institut Hospital del Mar d'Investigacions Mèdiques–Parc de Salut Mar, Barcelona, Spain. Further information regarding the BREATHE and schools participating in the BREATHE project can be found elsewhere (Sunyer et al., 2015).

2.2. Air pollution exposure during commuting, at school and at home

Information on the main mode of commuting to and from school and time spent during commuting was obtained from parents via questionnaires. Within the BREATHE participants, 1234 children reported only walking as the main mode of transport. We focused on walkers since mode choice is a determinant of the exposure to air pollutants during commuting (De Nazelle et al., 2012; Kaur and Nieuwenhuijsen, 2009). Estimation of the exposure during commuting other than walking implies several assumptions (e.g. indoor/outdoor ratios for each transport mode) that might lead to differential misclassification. For those BREATHE participants who walked to school, we identified the shortest walking route to school based on street networks (network distance) by using the network analyst extension from ArcGIS software v10.

We estimated the average concentration of NO_2, particulate matter ≤ 2.5 μm ($PM_{2.5}$) and BC ($PM_{2.5}$ absorbance) in each route using the Land Use Regression (LUR) models developed within the ESCAPE Project and described elsewhere (Eeftens et al., 2012). The validity of the ESCAPE LUR model for $PM_{2.5}$ Absorbance (proxy for BC) was previously evaluated by Nieuwenhuijsen et al. (2015) against personal BC measurements performed in a subsample of 53 BREATHE children with correlation coefficients of 0.59 and 0.68 for home and school, respectively. We did not have enough statistical power to validate the model for the commutes with the BREATHE subsample. We estimated the average concentration in the identified shortest route for each individual that reported commute by walking. Only the morning route (home to school) was considered, since these trips are more regular and they take place during the same time of the day across the schoolchildren. Moreover, concentrations of NO_2, $PM_{2.5}$ and BC ($PM_{2.5}$ absorbance) at every participant's home address and at school during the study period were also estimated using the ESCAPE LUR models. We also calculated the exposure taking into account the commuting duration, as a factor of concentration*time.

2.3. Cognitive development: working memory and inattentiveness

From January 2012 to March 2013, throughout two academic years, we evaluated the children's cognitive development (change in working memory and attention) every three months (resulting in four visits over a year) using computerized tests that took approximately 40 min to complete. These functions develop until adulthood. We used the n-back test for assessing working memory (Anderson, 2002) and the child Attention Network Test (ANT) to characterize inattentiveness, including the three attention networks (alerting, orienting, and executive control) (Rueda et al., 2004). We investigated the d prime (d', a measure of detection) from the three-back load for number stimuli. We selected the 3-back since this parameter showed a normal distribution while the 2-back task accuracy was truncated at 100% of correct responses and d' at 3.91 score. The selection of the number stimulus was informed by its evident dependency on age and limited learning effect compared to other stimuli (López-Vicente et al., 2016). The three-back test evaluates general cognitive functioning as well as functions such as fluid intelligence (from now on called working memory) (Shelton et al., 2010). Higher values of d' designate higher accuracy in the execution of the test. From the ANT measures, we evaluated the reaction time (RT) of the three attention networks and the hit reaction time standard error (HRT-SE; standard error of reaction time for correct responses), which is a measure of response speed consistency throughout the test (Conners and Multi-Health Systems, 2000). A higher HRT-SE means greatly variable reaction related to inattentiveness (Suades-González et al., 2017). These tests have been reported to have acceptable internal consistency, reasonable factorial structure, and good criterion validity and statistical dependencies for use in general population (Forns et al., 2014).

2.4. Covariates

Socio-demographic factors included child age, sex, parental education (primary or less/secondary/university) and employment