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# Recent *versus* chronic exposure to particulate matter air pollution in association with neurobehavioral performance in a panel study of primary schoolchildren

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ABSTRACT

Children's neuropsychological abilities are in a developmental stage. Recent air pollution exposure and neurobehavioral performance are scarcely studied. In a panel study, we repeatedly administered to each child the following neurobehavioral tests: Stroop Test (selective attention) and Continuous Performance Test (sustained attention), Digit Span Forward and Backward Tests (short-term memory), and Digit-Symbol and Pattern Comparison Tests (visual information processing speed). At school, recent inside classroom particulate matter ≤2.5 or 10 μm exposure ($PM_{2.5}$, $PM_{10}$) was monitored on each examination day. At the child's residence, recent (same day up to 2 days before) and chronic (365 days before examination) exposures to $PM_{2.5}$, $PM_{10}$ and black carbon (BC) were modeled. Repeated neurobehavioral test performances ($n = 894$) of the children ($n = 310$) reflected slower Stroop Test ($p = 0.05$) and Digit-Symbol Test ($p = 0.01$) performances with increasing recent inside classroom $PM_{2.5}$ exposure. An interquartile range (IQR) increment in recent residential outdoor $PM_{2.5}$ exposure was associated with an increase in average latency of 0.087 s (SE: ±0.034; $p = 0.01$) in the Pattern Comparison Test. Regarding chronic exposure at residence, an IQR increment of $PM_{2.5}$ exposure was associated with slower performances in the Continuous Performance (9.45 ± 3.47 msec; $p = 0.007$) and Stroop Tests (59.9 ± 26.5 msec; $p = 0.02$). Similar results were obtained for $PM_{10}$ exposure. In essence, we showed differential neurobehavioral changes robustly and adversely associated with recent or chronic ambient exposure to PM air pollution at residence, i.e., with recent exposure for visual information processing speed (Pattern Comparison Test) and with chronic exposure for sustained and selective attention.



## 1. Introduction

Polluted air is a complex mixture of water vapor, gases, and solid particles. Evidence is growing that ambient air pollution exposure may be neurotoxic (Block and Calderon-Garciduenas, 2009). When small particles (particulate matter with a diameter < 10 μm, $PM_{10}$) deposit in the lungs, they may trigger the release of inflammatory mediators in the systemic circulation (Van Eeden et al., 2001; Sawyer et al., 2010). Fine particles (PM < 2.5 μm, $PM_{2.5}$) can also translocate into the circulation leading to increased systemic inflammation (Furuyama et al., 2009), which may adversely affect the central nervous system (CNS) (Clark et al., 2010; Cunningham, 2013). Besides the link with systemic inflammation, particles <0.1 μm might also cause harm to the CNS in a more direct way by crossing the blood-brain-barrier or by retro-axonal translocation via the olfactory nerve (Oberdörster et al., 2004; Elder et al., 2006). Experimental studies in rodents demonstrated a wide range of biological CNS effects of air pollution exposure including a pro-inflammatory cytokine response, glial activation, oxidative stress, changes in gene expression, and perturbations of levels and turnover of neurotransmitters (Gerlofs-Nijland et al., 2010; Levesque et al., 2011; MohanKumar et al., 2008; Suzuki et al., 2010; Tin Tin Win et al., 2006; Tsukue et al., 2009). Epidemiological studies in adults showed that long-term exposure to traffic-related air pollution may contribute to neurodegenerative diseases, such as Parkinson's and Alzheimer's disease (Ritz et al., 2016; Kioumourtzoglou et al., 2016). Studies in children

*Abbreviations:* $PM_{10}$, $PM_{2.5}$, particulate matter with a diameter ≤ 10 or 2.5 μm; BC, black carbon; IQR, interquartile range; RPMR, residential proximity to major roads; NES, neurobehavioral evaluation system.

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suggested that neurotoxic effects of air pollution may translate into observable deterioration of neurobehavioral performance. In children from Boston of approximately 10 years old, average lifetime residential levels of black carbon (BC) were inversely associated with attention, memory, learning, and intelligence (Suglia et al., 2008; Chiu et al., 2013). In another prospective cohort study, prenatal air pollution exposure as assessed by personal monitoring of polycyclic aromatic hydrocarbons was inversely associated with neurodevelopmental characteristics (intelligence, behavior) in early childhood (Edwards et al., 2010; Perera et al., 2006; Perera et al., 2012). Furthermore, cross-sectional studies also reported inverse associations between neurobehavioral performance of children and indicators of chronic air pollution exposure (Van Kempen et al., 2012; Wang et al., 2009). Recently, it has been shown that children exposed to high traffic-related air pollution have a smaller enhancement in neurobehavioral development after one year in comparison to children exposed to low air pollution (Sunyer et al., 2015). We found that traffic exposure in adolescents, as reflected by a composite factor combining information about traffic density, time spent in traffic, and urinary concentration of *trans,trans*-muconic acid, was negatively associated with sustained attention (Kicinski et al., 2015).

Despite these studies are suggestive of a neurobehavioral performance deficit associated with fine particle air pollution, there is still insufficient evidence on the consistency of these associations (Clifford et al., 2016). Neurobehavioral changes associated with recent air pollution exposure (i.e., exposure on the day and a few days before the neurobehavioral examination) have been scarcely studied. The aim of this study was to investigate with repeated measures whether neurobehavioral performance was differently associated with recent versus chronic air pollution exposure in a panel of primary schoolchildren.

## 2. Materials & methods

### 2.1. Study population

This investigation was part of the COGNAC (COGNition and Air pollution in Children) study. Between 2011 and 2013, we invited children (grades three to six) from three primary schools in Flanders (Belgium) to participate. These schools were located in urban areas with a substantial amount of traffic (Fig. 1). Typical particulate matter air pollution ($PM_{2.5}$) in the recruitment area was mainly characterized by the following components: elemental carbon (3%), organic mass (20%), sea salt (5%), ammonium (12%), nitrate (21%), ammonium sulfate (18%) and mineral dust (3%) (VMM, 2016).

The parents of the participants filled out a questionnaire to collect information about the current and previous residential addresses, the socioeconomic status of the family, the smoking behavior of the family members, and they provided informed consent for participation. Socioeconomic status was based on the mother's education (up to high school diploma; college or university diploma) and the highest rank of occupation of either parents (unemployed or unqualified worker; qualified worker, white collar assistant, or teaching staff; self-employed, specialist or member of management). The out-of-school sport activities were defined as “none” (no out-of-school sport activities), “low” (≤3 h per week), “middle” (>3 to <6 h per week) and “high” (≥6 h per week). The study protocol was approved by the medical ethics commissions of Hasselt University and the East-Limburg Hospital.

In total, 334 children agreed to participate in the study, however 24 had to be removed from the database because of missing data on mother's education and/or occupation of the parents, passive smoking exposure, or residential outdoor exposure. Of the 310 children, 277 (89.3%) were examined three times, 30 (9.7%) two times, and 3 (1%) once, amounting to a total number of 894 examinations. The examinations took place between December 2011 and February 2014 on Monday, Tuesday, Thursday, and Friday between 9:00 a.m. and 2:00 p.m. The mean (SD) period of time between two consecutive examinations was 41 (23) days. Each neurobehavioral examination was scheduled for the same time of the day for the same child, but in some cases it was not possible due to school activities. For the same child, the time of the day at which the neurobehavioral examinations took place differed on average (SD) 24 (48) min.

### 2.2. Assessment of PM air pollution exposure

#### 2.2.1. Air pollution measurements at the schools

At the schools, we used portable devices (AEROCET 531; MetOne Instruments Inc., Grants Pass, OR, USA) to carry out area measurements of particulate matter [PM with a diameter ≤ 2.5 μm ($PM_{2.5}$) and ≤10 μm ($PM_{10}$)] inside the classroom on the examination day (Table 1). Continuous air monitoring was carried out from 9 to 12 a.m. as 2 min interval measurements which were averaged and expressed as μg/m$^3$.

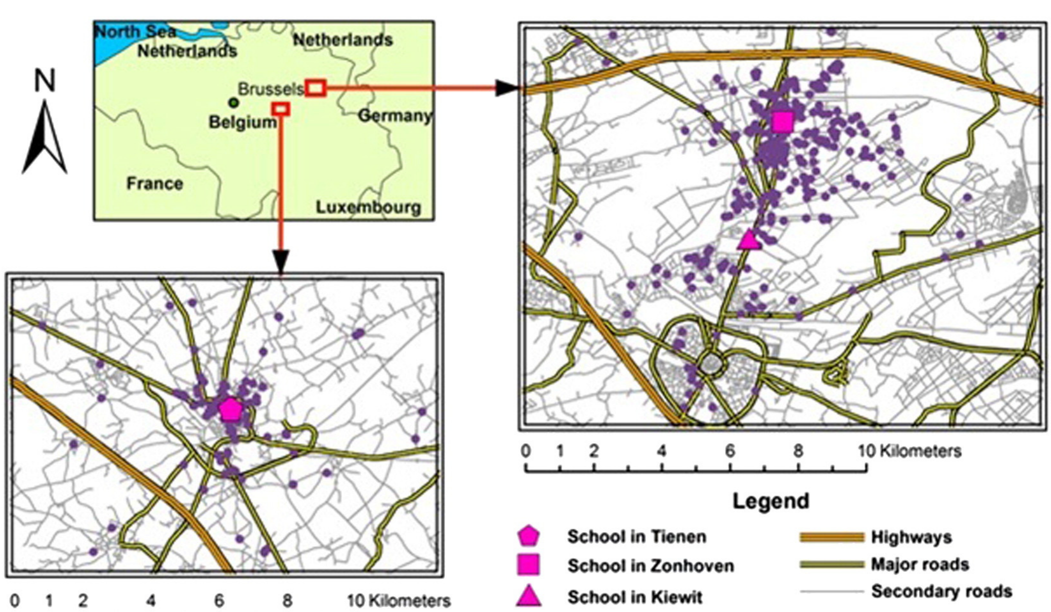


**Fig. 1.** Study area with indication of the school locations in the three municipalities and the road system. Dots represent the residential addresses of the schoolchildren.