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Neurobehavioral performance in adolescents is inversely associated with traffic exposure

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ABSTRACT

On the basis of animal research and epidemiological studies in children and elderly there is a growing concern that traffic exposure may affect the brain. The aim of our study was to investigate the association between traffic exposure and neurobehavioral performance in adolescents. We examined 606 adolescents. To model the exposure, we constructed a traffic exposure factor based on a biomarker of benzene (urinary *trans,trans*-muconic acid) and the amount of contact with traffic preceding the neurobehavioral examination (using distance-weighted traffic density and time spent in traffic). We used a Bayesian structural equation model to investigate the association between traffic exposure and three neurobehavioral domains: sustained attention, short-term memory, and manual motor speed. A one standard deviation increase in traffic exposure was associated with a 0.26 standard deviation decrease in sustained attention (95% credible interval: −0.02 to −0.51), adjusting for gender, age, smoking, passive smoking, level of education of the mother, socioeconomic status, time of the day, and day of the week. The associations between traffic exposure and the other neurobehavioral domains studied had the same direction but did not reach the level of statistical significance. The results remained consistent in the sensitivity analysis excluding smokers and passive smokers. The inverse association between sustained attention and traffic exposure was independent of the blood lead level. Our study in adolescents supports the recent findings in children and elderly suggesting that traffic exposure adversely affects the neurobehavioral function.

1. Introduction

There is a growing public health concern that traffic-related air pollution may be harmful to the brain (Calderon-Garciduenas et al., 2013). Inhaled ultrafine particles translocate to the brain (Elder et al., 2006; Oberdörster et al., 2004) and are able to induce oxidative stress in the neuronal cells (Block et al., 2004; Levesque et al., 2011). Exposure to traffic-related air pollution increases pro-inflammatory mediators in the systemic circulation (Kido et al., 2011), which affects the brain function (Cunningham et al., 2009; Qin et al., 2007). In line with these results, multiple experimental studies in rodents have shown that airborne particulate matter increases biomarkers of neuroinflammation (Campbell et al., 2005; Gerlofs-Nijland et al., 2010), which may lead to a deterioration in cognitive performance and play a crucial role in the development of neurological disorders (Clark et al., 2010; Lee et al., 2008). Neurotoxicological changes have also been observed in humans exposed to air pollution (Calderon-Garciduenas et al., 2008, 2012). Studies comparing children living in a city with much air pollution to those living in clean areas revealed that exposure to air pollution was associated with a deposition of particulate matter in bulb neurons,

Abbreviations: t,t-MA-U, *trans,trans*-muconic acid in urine; DWTD, distance-weighted traffic density; CI, credible interval; SD, standard deviation.

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neuroinflammation (as indicated by an up-regulation of cyclooxygenase-2, interleukin-1β, and monocyte chemoattractant protein), low concentrations of cytokines involved in neuroprotection, and accumulation of amyloid β42 (Calderon-Garciduenas et al., 2008, 2012).

A number of recent studies have observed a negative association between air pollution exposure and neurobehavioral outcomes. Average lifetime concentrations of residential black carbon were negatively associated with intelligence in children between 8 and 11 years of age (Suglia et al., 2008) and with sustained attention in children between 7 and 14 years of age (Chiu et al., 2013). In two independent cohorts, children who had a higher prenatal exposure to ambient polycyclic aromatic hydrocarbons as evaluated by personal air monitoring of the mothers showed a lower IQ at the age of five (Edwards et al., 2010; Perera et al., 2009). In elderly, a higher particulate matter exposure was associated with a decline in cognitive performance (Gatto et al., 2014; Power et al., 2011; Ranft et al., 2009; Weuve et al., 2012). To date, the neurobehavioral effects of traffic exposure in age categories other than young children and elderly have received little attention.

A study of 200 Flemish adolescents showed that those living in suburbs crossed by busy highways (>80,000 vehicles per day) had higher urinary levels of *trans,trans*-muconic acid (*t,t*-MA-U) than those living in a control area with little traffic (Staessen et al., 2001), thus highlighting the usefulness of this metabolite of benzene as a proxy-biomarker for traffic exposure. Several other studies have shown that exposure to vehicle exhaust is associated with an increase in the *t,t*-MA-U levels (Amodio-Cocchieri et al., 2001; Arayasiri et al., 2010; Navasumrit et al., 2005). Here, we investigated in another group of Flemish adolescents whether traffic exposure may affect neurobehavioral domains, i.e., sustained attention, short-term memory, and manual motor speed. A major challenge in studies of health effects of traffic-related air pollution involves accurate assessment of the exposure. In order to address this challenge, we applied structural equation modeling, which allowed us to utilize different sources of information about the exposure including traffic density, time spent in traffic, and *t,t*-MA-U.

2. Materials and methods

2.1. Study population and data collection

A detailed description of the study population can be found elsewhere (Kicinski et al., 2012). Briefly, as part of a biomonitoring program for environmental health surveillance in Flanders, Belgium, we recruited between 2008 and 2011 grade nine high school students in two specific areas, Genk (n = 197) and Menen (n = 199), and from the general population of Flemish adolescents (n = 210). Genk and Menen were selected due to a high level of industrial activities in these cities and their surroundings. In Flanders, a region of Belgium with approximately 6 million inhabitants on a surface area of only 13,522 km^2, the number of vehicles exceeded 3.7 million in 2009 (De Geest et al., 2011). In the same year, these vehicles traveled 56.4 billion km (De Geest et al., 2011). With a dense network of roads including over 800 km highways, 6200 km other major roads, and over 64,000 km secondary roads (De Geest et al., 2011), every resident is exposed to traffic at least to some extent.

Two weeks before the study, participants and their parents received questionnaires to fill out. The questionnaire for adolescents included questions about their smoking behavior. The questionnaire for parents included questions about their education level, income, occupation, and the amount of time spent in traffic by their children. We asked how many minutes the child spends per day traveling by car, bus, or tram during the week and during the weekend. The high correlation between the amount of time spent in traffic by adolescents during a weekday and the logarithm of the distance between the school and home locations (r = 0.52) confirmed the validity of the questionnaire. Each participant received a plastic bottle and was asked to collect a first morning urine sample at the day of the neurobehavioral examination. However, 1.3% of the participants collected a urine sample in the evening preceding the neurobehavioral examination and for 19.3% of the adolescents a urine sample was collected at school during the examination. For most participants (85%), the urine sample was collected not more than 4 h before the administration of the neurobehavioral tests. The samples were stored in a cooler (4 °C) during transportation and kept frozen at −20 °C until analysis. Both parents and teenagers provided informed consent for participation. The study was approved by the Ethical Committee of the University of Antwerp.

2.2. Distance-weighted traffic density (DWTD)

We constructed a DWTD measure, which assumes that airborne exhaust pollutants spread in a Gaussian manner (Kashima et al., 2011; Pearson et al., 2000; Wilhelm and Ritz, 2003). In this approach, the impact of traffic is modeled as a function of the traffic density and the distance to the road according to the following equation:

$$w = \frac{1}{0.4 * \sqrt{2\pi}} \exp\left[-\frac{1}{2} * \frac{\left({}^{D}/_{150}\right)^2}{(0.4)^2}\right]$$

where D is the distance to the road in meters and w the corresponding weight factor (Fig. 1). The shape of the equation reflects the assumption that 96% of the emissions disperse at 150 m from the road, which is based on research that investigated the dispersion of vehicle exhaust pollutants (Zhu et al., 2002). We calculated DWTD for each school and home location by adding up the traffic density in the neighborhood weighted by the distance (Fig. 1). The resulting values were log transformed to normalize the distribution. The length of the roads was calculated using the Geographical Information System (GIS, ArcMap version 10.0). Information about the average number of vehicles on highways and other major roads was available from a network of measuring stations run by the Department of Mobility and Public Works. In order to estimate the number of vehicles on non-major roads, we used

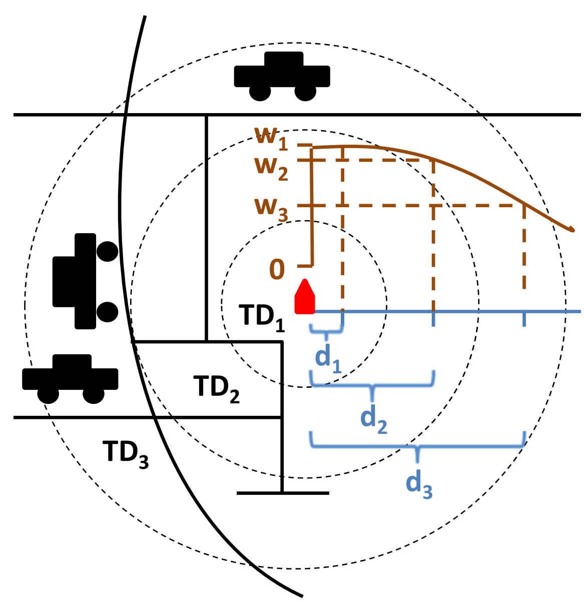

Fig. 1. Distance-weighted traffic density (DWTD). For each location, $DWTD = TD_1w_1 + TD_2w_2 + TD_3w_3 + \ldots + TD_{50}w_{50}$, where TD_i is the traffic density within ring i and w_i is the corresponding weight, $i = 1, \ldots, 50$. The traffic density is expressed as the total number of kilometers traveled by all vehicles during one day. We calculated traffic density for each road by multiplying traffic counts (the number of cars passing a measuring station during one day) by the length of the road. w_i is a value of a Gaussian function for d_i, where d_i is the distance to a middle point of ring i. We used $d_1 = 5$ m, $d_2 = 15$ m, $d_3 = 25$ m, …, $d_{50} = 495$ m, which produced accurate results within a relatively short computation time. For $i > 50$, TD_iw_i equaled approximately 0.