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Cyclist exposure to black carbon, ultrafine particles and heavy metals: An experimental study along two commuting routes near Antwerp, Belgium

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ABSTRACT

Urban environments typically exhibit large atmospheric pollution variation, in both space and time. In contrast to traditional monitoring networks suffering from a limited spatial coverage, mobile platforms enable personalized high-resolution monitoring, providing valuable insights into personal atmospheric pollution exposure, and the identification of potential pollution hotspots. This study evaluated personal cyclist exposure to UFPs, BC and heavy metals whilst commuting near Antwerp, Belgium, by performing mobile measurements with wearable black carbon (BC) and ultrafine particle (UFP) instruments. Loaded micro-aethalometer filterstrips were chemically analysed and the inhaled pollutant dose determined from the exhibited heart rate. Considerable spatial pollutant variation was observed along the travelled routes, with distinct contributions from spatial factors (e.g. traffic intersections, urban park and market) and temporary events. On average 300% higher BC, 20% higher UFP and changing elemental concentrations are observed along the road traffic route (RT), when compared to the bicycle highway route (BH). Although the overall background pollution determines a large portion of the experienced personal exposure (in this case 53% for BC and 40% for UFP), cyclists can influence their personal atmospheric pollution exposure, by selecting less exposed commuting routes. Our results, hereby, strengthen the body of evidence in favour of further policy investments in isolated bicycle infrastructure.

1. Introduction

Atmospheric pollution levels in typical heterogeneous urban environments are known to vary greatly in space and time. While the spatial variation is mainly linked to differences in traffic intensity, urban topology and distance to individual pollutant sources, temporal variation consists of day-to-day (mainly meteorology and urban background fluctuations), within-day (mainly due to traffic dynamics) and microscale variability (single short-lived events) (Van den Bossche et al., 2015). As traditional stationary air quality monitoring networks are limited in terms of spatial coverage, mobile monitoring platforms, enabling personalized and high-resolution monitoring, have become increasingly popular during the last decade (Van den Bossche et al., 2015; Elen et al., 2013; Cai et al., 2014; Dewulf et al., 2015; Int Panis et al., 2010; Gerike et al., 2016). Especially for atmospheric pollutants experiencing large spatiotemporal variation in urban environments (e.g. ultrafine particles (UFPs), black carbon (BC), NO_x, …), mobile monitoring provides valuable insights into the atmospheric pollution range that city dwellers are exposed to in daily life, and potential occurrences of local hotspot locations which can consequently be targeted by policy makers and urban developers.

Atmospheric aerosols, ranging from several nanometers to approximately 100 nm in diameter, are composed of primary particles, emitted from both anthropogenic activities and natural sources, and secondary particles formed by gas-to-particle conversion processes including nucleation and condensation (Querol et al., 2011; Donaldson et al., 2001). Current air quality legislation focuses on monitoring, limiting and reducing mass concentrations of these airborne particles. However, recent toxicological and epidemiological research suggests that particle numbers may constitute better links to health endpoints than mass concentration (Harrison et al., 2000; Kelly and Fussell, 2012; Baldauf et al., 2016). Especially ultrafine particles (UFPs), consisting of atmospheric aerosols smaller than 100 nm (< 0.1 µm), are able to penetrate deeply into the respiratory system, enter the bloodstream and even cross the blood-brain barrier to end up in brain tissue, inducing inflammation and, potentially leading to cardiovascular and respiratory health conditions (Baldauf et al., 2016; Reche et al., 2011; Viana et al., 2012). Particle number concentrations have been shown to vary

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considerably in urban environments (Kumar et al., 2011; Frijns et al., 2013; Hofman et al., 2016; Zhu et al., 2002; Peters et al., 2014; Van Poppel et al., 2013), having important implications in terms of individual exposure for people moving around cities.

BC is an important constituent of fine (< 2.5 µm) particulate matter (mainly between 20 and 150 nm), a good indicator of combustion-related air pollution and has shown to relate to cardiovascular mortality and contribute to the risk of developing cancer (Janssen et al., 2012; Koelmans et al., 2006). Short-term fluctuations in personal black carbon exposure have proven to be associated with rapid changes in carotid arterial stiffening (Provost et al., 2016). Similarly to UFPs, atmospheric BC concentrations have been shown to vary considerably across urban environments (Viana et al., 2012; Peters et al., 2014; Van Poppel et al., 2013; Tunno et al., 2016).

Besides their direct toxicity, atmospheric aerosols act as carriers of various toxic constituents like polycyclic aromatic hydrocarbons (PAHs) or heavy metals. The toxicity of heavy metals and other chemical compounds depends on several factors including the dose, route of exposure, and chemical species, as well as the age, gender, genetics, and nutritional status of exposed individuals. Because of their high degree of toxicity, the metalloid arsenic (As), and the metals cadmium (Cd), chromium (Cr), lead (Pb), and mercury (Hg) rank among the priority substances that are of public health significance (Tchounwou et al., 2012; Martin and Griswold, 2009).

This study focuses on commuter exposure to UFPs, BC and heavy metals during rush hour periods in the city of Antwerp (Belgium). Two commuting routes connecting the residential and work address of the corresponding author (Jelle Hofman; age: 31; sex: male; nationality: Belgian) were considered; (1) BH; a cycling route mostly following the Antwerp-Mechelen bicycle highway, and (2) RT, which is a little shorter but runs along roads with car traffic (Fig. 1). Both commuting routes were cycled from January till March 2017, whilst carrying a backpack containing a MicroAeth® BC monitor (Aethlabs, US) and a P-Trak ultrafine particle counter (0.02–1 µm; Model 8525, TSI, US), performing continuous high temporal resolution measurements (10 s). The loaded filter strips of the micro-aethalometer were chemically analysed for their elemental content. The aim was to determine personal UFP, BC and heavy metal exposure along both commuting routes and calculate the exhibited pollution dose from the heart rate function.

2. Materials & methods

Due to the high temporal variability of the considered urban pollutants, mobile monitoring can only be considered representative if large data series, representing the range of meteorological and traffic conditions, are collected (Van den Bossche et al., 2015; Peters et al., 2014; Padró-Martínez et al., 1994). To target an uncertainty of 50% (25% and 50% are applied as data quality objectives in the European 2008/50/EC directive), Van den Bossche et al. (2015) reported that 5–11 (median of 8) repeated monitoring runs satisfy to estimate the average BC concentration in urban environments. In our study, 10 monitoring runs per week (5 working days) were performed along two commuting routes, consisting of both morning (~6:00–9:00 h) and evening (~15:00–19:00 h) rush hour runs. For each commuting route 40 repeated runs were performed, between 6/1/2017 and 23/3/2017 (Table S1). To consider potential seasonal effects, commuting routes were alternated every week. The average cycling speed was 21.4 km h^{-1} (5.98 m s^{-1}), the MicroAeth® and P-Trak were set to a 10 s monitoring resolution and geographical and heart rate data (TomTom Runner 2) were obtained at a 1 s resolution.

Fig. 1. Overview of the considered road traffic (RT; left) and bicycle highway (BH; right) commuting routes that were monitored whilst cycling (tubing backpack). Residential and work address locations are denoted by the respective icons, while the reference monitoring station (42R817, VMM), located along both cycling routes, is denoted by the black circle.