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Short communication

Daily personal exposure to black carbon: A pilot study

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HIGHLIGHTS

- Black carbon (BC) is an important component of air pollution.
- We measured personal exposure to BC over twenty 24 h periods.
- We report impacts of wood-fired heaters, transport mode, and cabin ventilation.
- We suggest simple measures to reduce BC exposure.

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ABSTRACT

Continuous personal monitoring is the benchmark for air pollution exposure assessment. Black carbon (BC) is a strong marker of primary combustion like vehicle and biomass emissions. There have been few studies that quantified daily personal BC exposure and the contribution that different microenvironments make to it. In this pilot study, we used a portable aethalometer to measure BC concentrations in an individual's breathing zone at 30-s intervals while he performed his usual daily activities. We used a GPS and time-activity diary to track where he spent his time. We performed twenty 24-h measurements, and observed an arithmetic mean daily exposure concentration of 603 ng/m^3. We estimated that changing commute modes from bus to train reduced the 24-h mean BC exposure concentration by 29%. Switching from open windows to closed windows and recirculated air in a car led to a reduction of 32%. Living in a home without a wood-fired heater caused a reduction of 50% compared with a wood-heated home. Our preliminary findings highlight the potential utility of simple approaches to reduce a person's daily BC exposure.

1. Introduction

Ambient particulate matter <2.5 μm ($PM_{2.5}$) is the leading environmental risk factor for mortality globally. In 2013, $PM_{2.5}$ was responsible for 2.93 million deaths, an increase of 30% from 1990 (IHME, 2015). Accurate estimates of people's exposure to air pollution are required to understand the range and magnitude of its health impacts. Continuous measurement of the pollutant concentrations that a person comes into contact with is the best way to assess their exposure (Brauer et al., 2008; Nieuwenhuijsen, 2003). This allows the contribution of different activities and microenvironments to their total daily exposure to be quantified, which provides a basis for identifying where and how exposures can be reduced (Wallace and Ott, 2011).

Black carbon (BC) is a specific marker of primary combustion such as vehicle and biomass emissions (Cai et al., 2013). BC has been associated with greater effects on cardiorespiratory morbidity and mortality than $PM_{2.5}$, which has a more heterogeneous chemical composition (Janssen et al., 2011). Measurements of personal exposure to BC have been reported recently in 'hot-spots' like transport modes (e.g., Dons et al., 2012; Hankey and Marshall, 2015; Li et al., 2015). However, few studies have assessed total daily exposures over 24 h, which makes it difficult to identify the microenvironments that make the greatest contribution and how exposure can be reduced. In this pilot study, we aimed to: (1) quantify an individual's total daily personal BC exposure, and; (2) apportion it between different microenvironments.

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2. Methods

2.1. Setting

Our study was performed in Brisbane, the state capital of Queensland and Australia's 3rd largest city (population ~2.2 million), and Eden, a small rural town (population ~4000) located at the southern coastal extent of the state of New South Wales approximately 1110 km SW of Brisbane. The reason for including two markedly different geographic settings was to incorporate as much variability as possible in BC sources that contribute to personal exposure. Eden experiences a temperate maritime climate (mean annual daily temperature = 15.0 °C) with cool winters characterised by widespread use of wood-burning heaters (annual heating degree days at 18 °C reference temperature = 1370) (BoM, 2015). Brisbane has a subtropical climate (mean annual daily temperature = 20.5 °C) with mild winters (annual heating degree days = 470) (BoM, 2015). Our study ran from April to October, 2015, incorporating the Australian autumn, winter and spring.

2.2. Equipment

We used a microAeth portable aethalometer to measure BC (AethLabs model AE51, San Francisco, USA). The microAeth is the standard instrument for measuring personal exposure to BC (e.g., Cai et al., 2014; Dons et al., 2012), and it is relatively light and streamlined (280 g, 117 mm × 66 mm × 38 mm). The microAeth relies on light absorption at 880 nm of both BC accumulated on a filter strip as well as a clean reference section of the filter not exposed to BC. The attenuation of light is proportional to the mass change of BC accumulating on the filter (Cai et al., 2013).

Our microAeth was calibrated by the manufacturer prior to the study. We set it to a flow rate of 100 mL/min and logged average BC levels every 30 s. We selected these settings based on initial tests that indicated they were the best compromise between battery life, temporal resolution, and signal-to-noise ratio (AethLabs, 2015). We used a manufacturer-supplied cyclone with an upper cut point of 1.6 μm to protect the unit against optical interference due to coarse particles (Cai et al., 2014). The investigator (R.D.W.) attached the cyclone to their lapel, adjacent to their breathing zone.

We used a GPS module (QStarz model BT-1000XT, Taipei, Taiwan) to log the investigator's location and speed every 30 s. This device is well suited to time-location logging in personal exposure studies based on battery life, acquisition time, signal loss, memory capacity and positional accuracy (Wu et al., 2010). We also used a time-activity diary that divided each 24-h period into 15-min intervals.

2.3. Measurement approach

The investigator wore the microAeth and GPS over 20 complete 24-h periods, while he went about his normal daily activities. He did not undertake scripted activities. The 20 days were not measured continuously and each measurement was performed several days apart. Our measurements were performed on weekdays and weekends, with no preference to a particular day of the week or activity. The purpose was to quantify the investigator's exposure and the contribution of different microenvironments under realistic conditions. During overnight measurements, the investigator placed the microAeth on a bedside table.

2.4. Analysis

We processed raw microAeth data with the optimised noise-reducing averaging (ONA) algorithm (Hagler et al., 2011) recommended by the manufacturer and in recent literature (Li et al., 2015). The ONA algorithm accounts for negative values in BC data, which occur due to changes in environmental conditions (e.g., humidity) or vibration, while preserving the dynamics of the time series.

We determined the overall daily mean BC exposure of our investigator and the percent contribution of different microenvironments based on the exposures in each microenvironment (i.e., arithmetic mean concentration × mean time spent). We estimated the impacts of different microenvironments by substituting their concentrations into exposure calculations while holding all other exposures constant. To assess the sensitivity of the results to the mean concentration, we also substituted the 25th and 75th percentiles of BC measured in a microenvironment into our exposure estimates. These percentiles were selected to provide a realistic range around the mean in each microenvironment, rather than using the 5th and 95th percentiles which were less representative.

3. Results

Of the twenty 24-h measurements we attempted (480 h), data was successfully captured for 468 h (97.5%). Eighty-nine percent of data were collected in Brisbane and the remainder was collected in Eden. Measurements were performed in 2 non-smoking residential homes (1 with an enclosed and flued wood-burning heater, 1 without). In-vehicle measurements were collected in a 2008 model petrol-powered Volkswagen Jetta (with low fan setting, recirculate on, and windows fully closed, or no recirculation and windows open). Data were also collected when walking, cycling, outdoors, and on buses and trains.

Table 1 shows BC concentrations measured in different microenvironments. The arithmetic mean 24 h BC exposure concentration across all measurements was 603 ng/m^3 (s.d. = 1550 ng/m^3; geometric mean [s.d.] = 306 [3.7] ng/m^3). Highest concentrations were measured when commuting in a car with windows open and by bus with no open windows. Lowest concentrations were observed in the home without a wood-burning heater and when commuting by train. Residential indoor concentrations were about 2.5 times higher in the home with a wood-burning heater. Fig. 1 shows a 24-h time series collected in the wood-burning home, including the effects of indoor emissions and infiltrating outdoor smoke. In-vehicle concentrations were about 2.6 times higher when the windows were opened compared with closed windows and air recirculation.

The investigator spent 87.6% of his time indoors, all of which was spent in the residential setting as he worked from home. He spent 2.5% of their time outdoors and 9.8% commuting. Overall (i.e., all microenvironments combined), these locations accounted for 63.7%, 4.5% and 31.8% of his daily BC exposure, respectively. Being in a home with a wood-burning heater increased the indoor contribution to daily exposure from 62.7% (25th to 75th range: 41.0–67.2%) to 81.3% (range: 74.6–84.7%), with a 24-h mean daily exposure of 1172 ng/m^3 (range: 861–1429 ng/m^3). Commuting's contribution to BC exposure was 28.5% (range: 7.7–28.1%) in a car with windows up and air recirculated, with a 24 h exposure of 575 ng/m^3 (range: 445–572 ng/m^3). Opening the windows increased the contribution to 51.3% (range: 15.5–62.0%), with a 24-h exposure of 844 ng/m^3 (range: 486–1084 ng/m^3). Commuting by bus contributed 36% of daily BC exposure (range: 21.4–39.5%) with a 24 h exposure of 643 ng/m^3 (range: 523–679 ng/m^3). Train commutes contributed 10.5% of exposure (range: 5.9–11.4%), associated with a 24-h exposure of 459 ng/m^3 (range: 437–464 ng/m^3). Cycling and walking contributed 20% (range: 10.3–21.9%) and 22.9% (9.3–22%), respectively (24 h exposures: 514 ng/m^3 [range: 458–527 ng/m^3] and 533 ng/m^3 [range: 453–527 ng/m^3]).