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Personal exposure to Black Carbon in transport microenvironments

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ABSTRACT

We evaluated personal exposure of 62 individuals to the air pollutant Black Carbon, using 13 portable aethalometers while keeping detailed records of their time-activity pattern and whereabouts. Concentrations encountered in transport are studied in depth and related to trip motives. The evaluation comprises more than 1500 trips with different transport modes. Measurements were spread over two seasons. Results show that 6% of the time is spent in transport, but it accounts for 21% of personal exposure to Black Carbon and approximately 30% of inhaled dose. Concentrations in transport were 2–5 times higher compared to concentrations encountered at home. Exposure was highest for car drivers, and car and bus passengers. Concentrations of Black Carbon were only half as much when traveling by bike or on foot; when incorporating breathing rates, dose was found to be twice as high for active modes. Lowest 'in transport' concentrations were measured in trains, but nevertheless these concentrations are double the concentrations measured at home. Two thirds of the trips are car trips, and those trips showed a large spread in concentrations. In-car concentrations are higher during peak hours compared to off-peak, and are elevated on weekdays compared to Saturdays and even more so on Sundays. These findings result in significantly higher exposure during car commute trips (motive 'Work'), and lower concentrations for trips with motive 'Social and leisure'. Because of the many factors influencing exposure in transport, travel time is not a good predictor of integrated personal exposure or inhaled dose.

1. Introduction

In dedicated studies, it has been shown that traffic exposure may trigger health effects like myocardial infarction (Brook et al., 2010; Mills et al., 2007; Nawrot et al., 2011; Peters et al., 2004). Black Carbon (BC), or other traffic-related pollutants correlated with BC (NO_2, CO, Elemental Carbon, Ultrafine particles), may also provoke short or longer term health effects, e.g. cardiovascular disease (Baja et al., 2010; Gan et al., 2011; McCracken et al., 2010), adverse respiratory health outcomes (Lin et al., 2011; McCreanor et al., 2007; Patel et al., 2010) or neurological effects (Bos et al., 2011; Power et al., 2011; Suglia et al., 2007). Recently it has been stressed by Janssen et al. (2011) that BC is a useful new indicator for the adverse health effect of traffic-related air pollution.

Typically epidemiological studies try to relate an exposure metric to certain health effects in exposed or less exposed people. If using a generic exposure metric like population exposure or air quality measured at one specific place, it neglects the large contrast and variation in personal exposures that is important in epidemiological studies. For example, individuals traveling from hot spot to hot spot or professional drivers will be exposed to far higher concentrations compared to a hypothetical static population. In previous studies using activity-based models or personal monitors it is demonstrated that the transport activity, although short in duration, can be responsible for quite a large part of integrated personal exposure to combustion-related pollutants (Beckx et al., 2009; Dons et al., 2011; Fruin et al., 2004; Marshall et al., 2006). Understanding the variation in exposure can contribute to a more accurate exposure assessment and reduce misclassification of air pollution health effects. This is of major importance when trying to define the health effects of pollutants that are highly variable in time and space, like e.g. traffic-related air pollutants (Setton et al., 2011; Strickland et al., 2011; Van Roosbroeck et al., 2008).

In the light of understanding the role of transport activities on total accumulated exposure, a large personal monitoring campaign was set up. BC was measured on a 5-min time resolution, allowing air quality data to be linked with reported activities. In this paper the focus will be on exposure in traffic microenvironments; however transport is always considered as part of a complete 24 h diary, enabling the identification of trip motives and the calculation of the contribution of transport to integrated exposure and inhaled

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dose. BC was chosen as a pollutant because of its relevance for health, and because of the availability of suitable measurement devices. Moreover the interest of policy makers in BC was aroused due to emerging evidence on health effects and the impact of BC on global warming. In developed countries, motorized transport, and mainly diesel vehicles, are considered to be the most important source of BC, whereas in developing countries biomass burning may be important (Highwood and Kinnersley, 2006; Kirchstetter et al., 2008).

2. Materials and methods

Personal exposure to BC is measured with portable aethalometers (microAeth Model AE51, (AethLabs, 2011)), carried by 62 individuals for 7 consecutive days. During the sampling, participants were urged to meticulously keep track of their executed activities by reporting them in an electronic diary fitted with a GPS. On top of that, a short questionnaire asked for characteristics of the individual, the household and the residence. More details on the configuration of the devices, quality assurance and data analysis can be found in Dons et al. (2011). Sixteen people took part in a pilot study in summer 2010; half of them participated again in a more elaborate campaign in winter 2010–2011. The other half was either unwilling or unable to participate a second time. The winter campaign was supplemented with 38 new volunteers. Because we wanted to focus primarily on the impact of the time-activity pattern on personal exposure, we measured two people sharing the same residence. In summer 2010 all 8 couples were measured sequentially; in the winter campaign a maximum of three couples were measured simultaneously each week, for eight weeks in a row.

Some small adaptations were made in the winter campaign compared to the summer. The PARROTS software installed on a small handheld computer (Kochan et al., 2010), to fill in executed activities and trips, was somewhat simplified to further reduce respondent burden, without significant data loss. In the first campaign couples consisted of a full-time worker and a homemaker or part-time worker; in winter we relaxed this constraint: there was no further limitation on the work schedule. Other adaptations all concerned quality assurance and quality control (e.g. additional comparison with filter-based EC analysis and with a Multi-Angle Absorption Photometer (MAAP) measuring BC simultaneously at the official air quality monitoring stations).

To maintain data integrity, we corrected the aethalometer readings in different ways. First, all data showing an error code were excluded from the dataset (except for low battery events). In addition, we excluded data when the attenuation was above 75, whereas the instrument only gives an error code if attenuation is around 100. The value of 75 is a conservative lower limit as proposed by Virkkula et al. (2007), Hansen (2005) proposed the range of 75–125 as a suitable advisory limit for aethalometers. Finally we did an inter-comparison between all 13 devices used, to correct for device specific deviations (see Supplemental material for details, corrections were between 1% and 23%). The sample flow of all instruments, set at 100 ml min^{-1}, was checked before the measurement campaign.

During the sampling campaign, data from a fixed BC monitor on a suburban background location (station 40AL01 – Antwerpen Linkeroever, operated by the Flemish Environment Agency) was used to correct for non-simultaneous measurements (for the methodology, see Supplemental material).

Negative measurements were included into the analysis, because a temporary false decrease in measured absorption is offset in the next observation(s) (McBean and Rovers, 1998; Wallace, 2005). Only deleting the negative values would overestimate average BC concentrations.

To calculate the contribution of each activity to dose, a translation of exposure to inhaled dose is made by defining a minute ventilation per activity and per transport mode; gender was also taken into account. Inhalation rates are based on Allan and Richardson (1998) and Int Panis et al. (2010) (Supplemental material Table S2).

SAS 9.2 was used for data processing and statistical analysis.

3. Results

3.1. Study characteristics and time-activity patterns

All 62 volunteers participating in the measurement campaign measured their personal exposure for 7 consecutive days, 24 h a day, on a 5-min time resolution. This resulted in 124,992 single measurements, or more than 10,000 h of data. Some technical failures or human errors resulted in a data loss of approximately 4%. After data cleaning (excluding measurements with high attenuation or error signal), 17% of all data was not considered for further analysis. This is a rather high number, but it was necessary to maintain data integrity and, because of the very large dataset, a conservative limit could be used setting a high standard for the data analysis.

All volunteers were nonsmokers and not exposed to second-hand smoke at home. Everyone was of working age and there was a small bias toward higher education. Most participants worked in an office, and everyone worked in an indoor environment. All 62 participants had a driving license, but not all couples owned a car. Participants were living in Flanders, Belgium (Supplementary Figure S4). An overview of personal and household characteristics is given in Table 1 and car attributes are summarized in Supplementary Table S3.

Based on the activity diaries, it was calculated that volunteers spend 6.3% of their time (90 min per day) in transport; 35.5% of the day is spent sleeping (Table 2). The majority of trips were by car; but one third of all travel time was by slow modes (bike, on foot). There are relatively more trips as car passenger in the weekend and on off-peak hours compared to car drivers. Train and metro are generally used by commuters, with a large share of trips in traffic peak hours and on weekdays. Trips as car driver, cyclist, bus passenger or walking are spread in the same way throughout the day and throughout the week. All light rail and metro trips are in urban areas, whereas car trips are often on highways (>25% of total time) and on rural roads (>30% of total time). More than 70% of the time, trips by bike or on foot are on urban or suburban roads.

Table 1
Characteristics of the study participants.

		Summer	Winter
Personal characteristics			
Gender[a]	Male	8	23
	Female	8	23
Year of birth[a]	1951–1960	2	6
	1961–1970	7	12
	1971–1980	5	14
	1981–1990	2	14
Education/Highest degree[a]	Primary or secondary school	2	3
	Higher education, non-university	6	10
	Higher education, university	8	33
Working status[a]	Full-time worker	8	32
	Part-time worker	3	8
	Non-worker	5	6
Household characteristics			
Average household size[a]		3.88	3.65
Average number of cars per household[a]		1.38	1.48

[a] Results based on questionnaires filled in by the participants.