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Impact of time–activity patterns on personal exposure to black carbon

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ABSTRACT

Time–activity patterns are an important determinant of personal exposure to air pollution. This is demonstrated by measuring personal exposure of 16 participants for 7 consecutive days: 8 couples of which one person was a full-time worker and the other was a homemaker; both had a very different time–activity pattern. We used portable aethalometers to measure black carbon levels with a high temporal resolution and a PDA with GPS-logger and electronic diary. The exposure to black carbon differs between partners by up to 30%, although they live at the same location. The activity contributing most to this difference is transport: Average exposure in transport is 6445 ng m^{-3}, followed by exposure during shopping (2584 ng m^{-3}). Average exposure is lowest while sleeping (1153 ng m^{-3}) and when doing home-based activities (1223 ng m^{-3}). Full-time workers spend almost twice as much time in transport as the homemakers. As a result of the study design we measured in several different homes, shops, cars, etc. enabling a better insight in true overall exposure in those microenvironments. Other factors influencing personal exposure are: background concentrations and location of residence in an urban, suburban or rural environment.

1. Introduction

Personal exposure can be defined as the real exposure as it is experienced by individuals. When an individual is present at a certain place or in a certain microenvironment, he or she is exposed to the pollutant concentrations at this specific place. When an individual makes a trip from location A to location B, his personal exposure can be defined as the weighted average of concentrations present at each single location (WHO, 1999). Up till now, personal exposure is often estimated through the use of concentrations measured at fixed monitoring stations (Kaur et al., 2007; Sarnat et al., 2009). This is an approximation, as not only the ambient concentration is relevant, but also concentrations in different microenvironments (including indoors) and the whereabouts of individuals (Boudet et al., 2001; Jensen, 1999; Klepeis, 2006). Several studies have already examined the correlation between personal exposure and concentrations measured at fixed monitoring stations (Avery et al., 2010; Boudet et al., 2001; Gulliver and Briggs, 2004). This correlation shows a large spread between different studies, but overall correlation is stronger for longitudinal within-person studies, compared to cross-sectional studies (Avery et al., 2010). This indicates that differences between people and a large part of the spread within a subject can be explained by the activity pattern of the individuals and their daily environment.

Several studies are looking at the relationship between levels of exposure and health effects, but epidemiologists experience vast problems with exactly quantifying exposure. By using approximations for exposure, health effects can be wrongly assigned, or the strength of a relationship will not be sufficiently emphasized (Jerrett et al., 2005; Setton et al., 2011). Therefore researchers are looking at methods, either through direct measurements or indirect modeling, to reduce exposure misclassification (Int Panis, 2010).

We hypothesize that people, who are living at the same location, can nevertheless have a different exposure profile. The driving force for this difference will be the activity pattern and the subsequent microenvironments visited during a day. Short-term exposures may contribute significantly to daily average exposure. The aim of this study is to look at week-long exposure profiles with a high temporal resolution. Linking these data with detailed time–activity patterns will tell us what the impact is of an activity pattern on personal exposure. Two groups of people with a highly differential time–activity pattern were selected to demonstrate this.

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The pollutant looked at is black carbon (BC). BC has been used as an indicator of exposure to diesel exhaust (HEI, 2010), and it has been suspected as a contributor to global warming (Highwood and Kinnersley, 2006). Several researchers have recently stressed potential short and long-term cardiovascular, respiratory and neurodegenerative health effects of BC (Baja et al., 2010; McCracken et al., 2010; Patel et al., 2010; Suglia et al., 2007). Over the last 40 years BC-concentrations have declined rapidly in Europe, although the air has still moderate to heavy BC pollution. In the last decade concentrations seem to have leveled off possibly because of increasing emissions of diesel passenger cars.

2. Materials and methods

2.1. Study design and sampling method

Personal exposure measurements were performed in Belgium from May 2nd to July 8th 2010. 16 participants were asked to carry a device to measure BC-concentrations and to record their activities and whereabouts in an electronic diary. The study population comprises 8 couples, consisting of a full-time worker and a homemaker. Participants performed their regular activities; there were no restrictions but weeks where respondents were abroad or planned a weekend trip were excluded. All participants had to be nonsmokers. The presence of children and several characteristics of the residence were recorded, but they were not exclusion criteria. Each couple was measured sequentially for a 7-day period. Since the devices had to be reconfigured after each use, at least one day was in between the measurements of two couples, preventing reoccurring potential bias toward the end of the week (e.g. less accurate registration of activities (Bellemans et al., 2007)). In addition to the two personal measurements, a third measurement device was installed outside in front of the house of the couple, at the street side, to measure outdoor concentrations simultaneously. Two couples lived in an urban environment, two in a suburban zone and four couples were living in a more rural area.

An aethalometer – microAeth Model AE51 (MageeScientific, 2009) was used for personal monitoring of BC. This monitor is small and portable (250 g) and has a battery autonomy of up to 24 h when logging on a 5 min basis, as in this study. Inside is a small teflon-coated borosilicate glass fiber filter where BC-particles are captured. The aethalometer detects the changing optical absorption of light transmitted through this filter ticket. Every two days participants were asked to replace the filter to prevent saturation and to maintain measurement integrity. The pump speed was initialized at a rate of 100 ml per minute. One of the aethalometers was used for outdoor measurements at the place of residence. For this purpose a weather-proof housing was developed. For the personal measurements, participants could carry the aethalometer in their own backpack or handbag. Specific attention was drawn to the fact that the tube connected to the pump always had to be exposed to the air.

Activities, trips and GPS-logs were recorded on a small handheld computer or PDA. PARROTS (PDA system for Activity Registration and Recording of Travel Scheduling) was developed to facilitate this process and to minimize respondent burden (Bellemans et al., 2008). This tool was already deployed in a large scale survey on 2500 households, and a comparison was made with the traditional paper-and-pencil method. The electronic diary enforces all attributes of executed activities to be provided. Accordingly it resulted in a non-response of 0 and provides several consistency checks. It was concluded that PARROTS provides high quality time–activity data while no additional respondent attrition was observed (Kochan et al., 2010). A disadvantage is the limited battery autonomy of this device (approximately 4 h), implying the need to recharge the PDA at the workplace, at a friend's residence or in the car, since a car charger was provided as well.

Participants to this study were instructed to report each activity by picking one of thirteen predefined categories. In addition, they had to indicate the date, the start and end times, and the location (choosing from 4 predefined categories). Start and end times were expected to be precise on a 5 min time base. For trips, each respondent had to specify the start and end location and time, and the transport mode(s) used (choosing from 12 predefined categories). Finally, respondents had to indicate with whom they were performing an activity or trip.

In addition to the PDA and the aethalometers, a short questionnaire was handed over to each couple at the start of the measurements. Personal and household characteristics, e.g. birth year or car ownership, and housing characteristics, like the presence of air conditioning or location of the home next to a busy street, were asked to get an idea of possible confounders.

All participants were personally instructed on the aim of the study, how to use the devices and redirected to a help desk in case of problems during the week. No financial compensation was rewarded, but afterward everyone received a personalized report.

2.2. Quality assurance

Three aethalometers were used during the study. For the comparison of the different devices, they were put next to each other for over a week to test their correspondence. We measured in the relevant range (0–10,000 ng m^{-3}) in a real life situation, including indoor measurements and near transport. Correlation of the three devices was very high ($r > 0.96$). Further BC-concentrations were compared with a fixed monitoring station using the MAAP technique (Multi-Angle Absorption Photometry; station 42R801 Borgerhout, urban location), which was used as a reference value. Concentrations measured at the monitoring station AL01 (Antwerpen-Linkeroever) were considered as background concentrations.

When both partners were at home, they were asked to put the two personal aethalometers next to each other in the living room. In that way at least 7 h of common measurements were available for each day. Consequently we could do a daily check on the accuracy of these two aethalometers. This resulted in a Pearson correlation coefficient of 0.92, not knowing for sure that participants accurately followed our instructions.

The accuracy of the recorded activities and trips was checked by consulting the GPS-logs. The diary of the partner was used to check for uniformity (e.g. if one person indicated that he was doing an activity with his/her partner, it had to be present in the other diary as well). If an inconsistency was detected, the participants were contacted shortly after the measurement period and asked to clarify the situation.

2.3. Data analysis

All devices, the three aethalometers and the two PDA's, were synchronized at the start of each week. Activities, trips, GPS-logs and BC-concentrations were directly loaded into a database to minimize manual work and counter possible introduction of errors.

Negative measurements were included into the analyses (McBean and Rovers, 1998). Because the aethalometer detects the change in optical absorption, small shifts in the light beam or the filter ticket can cause a temporary decrease in measured absorption. Since the aethalometer computes the difference with the previous measurement, negative measurements are offset in the next observation(s). Missing values were caused by low battery events or when devices were intentionally switched off for