Atmospheric Environment 164 (2017) 270–279

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

# Contribution of time-activity pattern and microenvironment to black carbon (BC) inhalation exposure and potential internal dose among elementary school children

Hyeran Jeong, Donguk Park*

*Department of Environmental Health, Korea National Open University, Republic of Korea*

## HIGHLIGHTS

- Transportation and cooking were responsible for disproportionately high contributions to children's exposure to and potential dose of black carbon (BC).
- Children received intense exposure to BC when commuting by diesel vehicles and from charbroiling meat.
- Type of day, season, and gender modified contribution of activities/microenvironments to daily BC exposure and potential dose.

## ARTICLE INFO

*Article history:*
Received 17 January 2017
Received in revised form
30 May 2017
Accepted 4 June 2017
Available online 6 June 2017

*Keywords:*
Black carbon (BC)
Exposure
Potential inhaled dose
Time-activity pattern
Microenvironment (ME)
Contribution
Intensity

## ABSTRACT

The aims of this study were to quantify the contributions of activities or microenvironments (MEs) to daily total exposure to and potential dose of black carbon (BC). Daily BC exposures (24-h) were monitored using a micro-aethalometer micoAeth AE51 with forty school-aged children living in an urban area in Korea from August 2015 to January 2016. The children's time-activity patterns and the MEs they visited were investigated by means of a time-activity diary (TAD) and follow-up interviews with the children and their parents. Potential inhaled dose was estimated by multiplying the airborne BC concentrations (μg/m$^3$) we monitored for the time the children spent in a particular ME by the inhalation rate (IR, m$^3$/h) for the time-activity performed. The contribution of activities and MEs to overall daily exposure to and potential dose of BC was quantified. Overall mean daily potential dose was equal to 24.1 ± 10.6 μg/day (range: 6.6–46.3 μg/day). The largest contribution to BC exposure and potential dose (51.9% and 41.7% respectively) occurred in the home thanks to the large amount of time spent there. Transportation was where children received the most intense exposure to (14.8%) and potential dose (20.2%) of BC, while it accounted for 7.6% of daily time. School on weekdays during the semester was responsible for 20.3% of exposure and 22.5% of potential dose. Contribution to BC exposure and potential dose was altered by several time-activity parameters, such as type of day (weekdays vs. weekends; school days vs. holidays), season, and gender. Traveling by motor vehicle and subway showed more elevated exposure or potential dose intensity on weekdays or school days, probably influenced by the increased surrounding traffic volumes on these days compared to on weekends or holidays. This study may be used to prioritize targets for minimizing children's exposure to BC and to indicate outcomes of BC control strategies.



## 1. Introduction

Given the harmful potential of particulate matter (PM), ambient air $PM_{10}$ and $PM_{2.5}$ standards are currently being promulgated in Korea. In particular, combustion-related pollutants such as black carbon (BC) are known to be highly relevant to health and to induce a variety of negative health effects including respiratory diseases, cardiovascular problems, and biological aging (Delfino et al., 2010; Janssen et al., 2011; McCracken et al., 2010; Suglia et al., 2008; Zanobetti et al., 2011). Accurately measuring exposure to BC is of great importance for children since they undergo respiratory and cognitive development while

* Corresponding author. Department of Environmental Health, Korea National Open University, 86 Daehak-ro, Seoul 03087, Republic of Korea.
*E-mail address:* pdw545@gmail.com (D. Park).

http://dx.doi.org/10.1016/j.atmosenv.2017.06.007
1352-2310/

having an immature host defense system and show unique time-activity patterns (which are related with exposure) compared to adults (Bateson and Schwartz, 2007; Branco et al., 2014; WHO, 2006).

Researchers have evaluated exposure to BC by equipping subjects with micro-aethalometers and have estimated the contribution of activities or microenvironments (MEs) to their exposures and potential doses. Studies concerning personal monitoring of children have been restricted since they are high-cost, time-consuming, labor-intensive, and difficult to apply to young children (Branco et al., 2014; Jones et al., 2007; Monn, 2001). Nonetheless, Buonanno et al. (2013) assessed the BC exposure of 103 Italian children aged 8–11 and Rivas et al. (2015, 2016) monitored personal BC measurements for 45 Spanish children aged 7–10. Both consistently described transportation (exposure intensities defined as the ratios between the daily exposure contribution (%) and the daily time contribution (%) of 3.7 and 2.1 respectively) and cooking (exposure intensity of the former 1.4) as main activities contributing to overall daily exposure. Rivas et al. (2015) stressed the importance of indoor environment and schools, since they constituted large portions of daily time (82% and 31%, respectively) as well as integrated potential dose (56% and 37%, respectively). However, these studies did not measure individual exposures to BC on weekends, which may differ from those found during weekdays due to contrasting time-activity patterns by type of day. They also did not take into account gender or seasonal differences, which may affect time-activity pattern and, by extension, exposure to BC (Buonanno et al., 2012).

Our earlier work identified trips by diesel vehicle or subway and residential secondhand smoking as key factors influencing elevated inhalation BC exposure among Korean children based on the daily exposure assessment in an urban area (Jeong and Park, 2017). The aim of this study was to quantify the contribution of children's activities or MEs to their daily total exposure to and potential internal dose of BC. To this purpose, a detailed investigation of children's time-activity patterns and the MEs they visited was combined with continuous BC measurement. Comparison of the contribution to daily total exposure or potential dose of several time-activity parameters, such as type of day, season, and gender, would clarify the impact of time-activity pattern on exposure (potential dose) to BC.

## 2. Materials and methods

### 2.1. BC inhalation exposure by time-activity pattern and microenvironment (ME)

BC inhalation exposure assessments were carried out on forty 10-12-years-old children (10.9 ± 0.78) living in an urban area and attending a school that borders a four-lane road in Seoul, South Korea. The sampling campaign was conducted for 24 h per day from August 26, 2015 to January 28, 2016. It was conducted both on weekdays/school days and on weekends/holidays in order to elucidate a difference in exposure to BC by type of day which may influence time-activity pattern. Overall, measurements from forty children were included in the project. Further detail on the monitoring strategy including study subjects is provided in Jeong and Park (2017). On top of sampling, a short questionnaire was administered by children's parents to glean information on personal characteristics, housing conditions and possible confounders such as household smoking status. Each child carried a micro-aethalometer micoAeth AE51 (AethLab, San Francisco, CA, USA), a lightweight (280 g) portable BC sensor, in a waist bag. As air is drawn into the device at 100 ml/min, light-absorbing BC particles are deposited on a Teflon-coated borosilicate glass fiber filter which changes the attenuation of the transmitted light at 880 nm. In this way, the micro-aethalometer can report BC concentrations for 24 h while logging on a five-minute basis. We replaced filter strips before every sampling (i.e. every 24 h) to prevent the filter loading effect.

At the same time, children maintained a time-activity diary (TAD) every 15 min (40 min in the case of class), indicating children's main indoor or outdoor activities, start and end time of each time-activity, the location, and possible effect modifiers such as whether someone was cooking or smoking near the respondent and the state of natural ventilation. In the case of commuting, additional information on transport mode, fuel type, nearby road type, and vehicular idling or passing on the move was collected. The accuracy of the recorded activities and trips was checked by consulting the BC level logged. If any inconsistency was detected, the children or their parents were contacted shortly after the measurement period and asked to clarify the situation. After each sampling was finished, follow-up interviews were administered with the children in person and with their teachers or parents via telephone in order to gain more accurate and detailed information on activities or MEs with which they actually interacted.

After each sampling session, BC concentrations and information on activities and MEs were immediately loaded into a dataset to counter recall bias or data-handling errors. Negative values were included as they offset in the next observation(s) as the instrument computes the difference with previous measurements (McBean and Rovers, 1998), while missing values were treated as blanks instead of predicting certain values (Dons et al., 2011). BC concentrations showing error codes and one outlier monitored at a house with possible indoor smoking in winter (>320 μg/m$^3$) were removed to maintain data integrity. Being right-skewed, the BC data were natural-log-transformed to be more normally distributed for statistical analyses.

This study was conducted according to the principles outlined in the Helsinki declaration for research on human participants and was approved by the institutional review board of Korea National Open University (IRB No. ABN01-201601-22-04). All of the children and their parents provided written informed consent.

### 2.2. Estimation of BC potential inhaled doses

The potential inhaled dose absorbed by the children aged 10–12 was estimated by multiplying the airborne arithmetic BC concentrations (μg/m$^3$) we monitored for the time spent in a certain ME and inhalation rate (IR, m$^3$/h) for the time-activity executed. This calculation is based upon the assumption that aerosols are 100% inhaled into the respiratory system due to the sizes of particles (those with an aerodynamic diameter are approximately 99% inhalable via mouth) (ACGIH, 1985; Buonanno et al., 2013). IRs for the different activities were obtained from EPA (2008) and Buonanno et al. (2011) ranged from 0.31 m$^3$/h during sleeping and rest to 1.44 m$^3$/h during outdoor sports for children aged 6–10. For all commuting modes, these studies applied the same IR as that for sedentary activities, thereby underestimating the potential dose received while traveling in active modes. To better characterize potential dose by mode of transport, we therefore employed an IR for walking and cycling that equaled that for non-sedentary activities, whilst IR for trips by car or subway (children as passengers in general) matched that of sedentary activities (Table 1). Daily integrated potential dose was calculated by summing up partial potential dose for each ME/time-activity.