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Characteristics of peak concentrations of black carbon encountered by elementary school children

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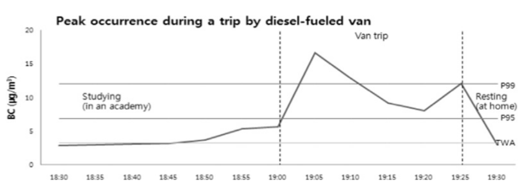
HIGHLIGHTS

- Children were exposed to short-term elevated BC levels
- Peak BC exposure levels ≥ time-weighted average differed significantly by activity and microenvironment.
- Commuting by diesel-fueled vehicles and charbroiling meat produced frequently-occurring BC peaks

GRAPHICAL ABSTRACT



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ABSTRACT

The objectives of this study were to examine characteristics of peak concentrations, including frequency, duration, and relative magnitude, and estimate its contributions to overall daily exposure to BC by activity and microenvironment. We assessed daily personal exposures from August 2015 to January 2016 (75.2% of weekdays and 24.8% of weekend days; 64.1% of school days and 35.9% of holidays) among forty 10–12 years old children living in the Seoul metropolitan area. These children were equipped with a microaethalometer (BC monitor) and recorded a time-activity diary. Pre-administrated questionnaires and follow-up interviews also provided information on children's time-activity patterns. Owing to the absence of a generally accepted threshold, peaks were alternatively defined as BC concentrations higher TWA, the 95th percentile, and the 99th percentile. Peak concentrations made substantial contributions to total daily exposure to BC (peaks ≥ TWA: 60%, peaks ≥95th-percentile: 19%, and peaks ≥99th-percentile: 6%). Average peak levels higher than TWA and the 95th percentile differed significantly by activity and ME. Transportation and cooking led to frequent peak occurrences which disproportionately contributed to daily integrated exposure relative to time spent in these activities. Walking was characterized by occasional brief but high-magnitude peaks exceeding the 99th percentile, which produced the most intense potential dose (0.09% of daily time spent on walking accounted for 1.6% of daily potential dose). It might be attributed to encounters with high emissions sources such as passing/idling vehicles and environmental tobacco smoke. Trips by diesel vehicle produced frequently occurring and long-duration peaks above the 95th percentile that contributed 2% to total daily exposure (corresponding time: 0.3%). Charbroiling meat incurred sustained peaks as intense as those in trips by diesel vehicles. Peaks during commuting showed relatively high exposure intensity on weekdays, possibly because of increased surrounding traffic volume on these days, while those during cooking accounted for a more elevated residential contribution to daily integrated exposure.

1. Introduction

Increasing attention has been paid to the importance of intense exposures of short duration (peaks) since the high concentrations involved produce a high dose rate into the body and target tissue that may alter metabolism, overload protective or repair mechanisms, and

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amplify tissue responses (Smith, 2001). Compared to $PM_{2.5}$ or $PM_{10,}$ black carbon (BC) has been suggested as a better indicator of harmful particulates emitted by combustion sources such as road traffic (Janssen et al., 2011; UN, 2012). Peak exposure to airborne particles or BC has been found to elicit acute health effects (Dockery and Pope, 1994; Verhoeff et al., 1996) and is likely to increase the risk of chronic health outcomes if regularly repeated over a long period (Schwartz, 2001). Emerging epidemiological evidence is indicating the adverse impact of peak concentrations to BC on health. Short-term elevations in BC have been found to lead to greater morbidity (Wang et al., 2013) and reduced lung function in both healthy adults (Strak et al., 2010) and in asthmatics (McCreanor et al., 2007; Spira-Cohen et al., 2011), a rapid DNA methylation decrement, altered heart rate variability, and increased onset of atrial fibrillation and arterial stiffness that conveys a higher risk of cardiovascular disease and aging (Baccarelli et al., 2009; Huang et al., 2013; Link et al., 2013; Provost et al., 2016), changes in brain function (Crüts et al., 2008), and epigenetic modulation of inflammatory pathways (Carmona et al., 2014). Briefer exposures to BC lasting two hours appeared to be more relevant to health compared to those lasting 48 h (Link et al., 2013), and those even within 1 h are associated with vascular changes (Provost et al., 2016). These effects may be more prominent among children owing to the vulnerability of early childhood development (Grigg, 2009).

Children, particularly those living in urban areas, can be exposed to intense levels of BC when they stay indoors (i.e., at home and school) in proximity to roads, play near traffic sources, and travel by motorized transport or subway, walk, and ride bicycles (Kaur et al., 2007). The children also face severe indoor pollution, especially when they stay in street-adjacent classrooms (Amato et al., 2014) or engage in high-generating activities, such as cooking. Peak concentrations of BC are difficult to assess through stationary monitoring, which is unable to track the rapid dynamics of an aerosol with which a child is in contact while the child is in motion by averaging pollutant levels measured from a fixed station (Manigrasso et al., 2013). This highlights the need for characterizing via personal monitoring peak concentrations actually faced by children. In recent studies on personal exposure measurements among children, researchers observed high occurrences of peaks, which could contribute significantly to daily BC exposure (Buonanno et al., 2013; Jeong and Park, 2017a; Rivas et al., 2016).

However, there has been scant research on childhood peak exposures to BC so far, and no consensus has been reached on a standard to define peaks. Prior studies on BC peak concentrations among adults have adopted different definitions of peaks and examined the number of peak events mainly in transport microenvironments (MEs). Peters et al. (2014) defined peaks as concentrations higher than the 95th-percentile concentration of BC received by cyclists along the routes studied and found high-occurring peaks in proximity to traffic sources (i.e., in tunnels or near busy crossroads). Abraham et al. (2014) described BC concentrations exceeding 10 μg/m^3 as peaks. They indicated underground transportation to be where peaks occur most often, which may be explained in part by iron interference due to the abundance of iron in the metro station (Jung et al., 2010), followed by bus travel. Maciejewska et al. (2015) proposed a BC threshold of 2.5 μg/m^3, which is equal to 10% of the WHO air quality guideline for short-term exposure to $PM_{2.5}$. These studies were descriptive in nature, and none of them looked specifically at various features of peaks, including at their contribution to overall daily BC exposure. To reflect real-life exposure among children and especially the peaks, it is necessary to investigate the exposed population, potential pathways of exposure, magnitude, frequency, duration, and time-pattern of contact with the pollutants (Hubal et al., 2000). This would also shed light on the relationship between peak concentrations and (acute) health effects (Wegman et al., 1992), which remains inconclusive, especially with regard to children (WHO, 2005).

Our past work has revealed the substantial contributions of transportation and cooking to overall daily BC exposure (dose) and detected the frequent occurrence of peaks during these activities based on a personal exposure assessment of children living in an urban area in Korea (Jeong and Park, 2017b). BC concentrations are strongly related to time-activity patterns, which are highly relevant when examining short-term peak concentrations (Dons et al., 2011; Provost et al., 2016). We therefore linked children's time-activity data with peaks in personal BC measurements. The present work will focus on the characterization of peak concentrations to BC among children. For this purpose, we will i) examine frequency, duration, magnitude of peaks, ii) quantify their contribution to daily integrated exposure, and iii) identify specific activities or MEs affecting peak events.

2. Materials and methods

2.1. Personal BC exposure measurements

We performed daily personal monitoring of BC on children aged 10–12 from August 2015 to January 2016. A total of forty children (17 boys and 23 girls) participated in the sampling campaign. They are likely to be subject to BC pollution for environmental, behavioral, and physiological reasons. Over one half of the participants lived adjacent to multi-lane roads (57%) and had a smoking parent (52.5%: smoking inside the house, 15%; smoking outside the house, 37.5%). One out of eight children resided in below-ground-level housing. As a majority of the children lived near the school, it was common for them to walk to school (65%) while 22.5% of them traveled a long-distance (>1 km) trip to school by bus, car, or subway. However, those who attend private academies mostly commute by diesel-powered vans and minibuses (44%). Three quarters of the children had preexisting allergic or respiratory symptoms. The children were living in the Seoul metropolitan area and attending the same school. To determine whether exposure differs by time-activity pattern, sampling took place both on weekdays/school days and on weekends/holidays (Sampling period consisted of weekdays (75.2%) and weekend days (24.8%); school days (64.1%) and holidays (35.9%).).

They were encouraged to follow their daily routines and carried a microaethalometer AE-51 (AethLab, San Francisco, CA, USA), a portable BC monitor as much as possible. One-day measurement for each child was conducted for 24 h. The instrument was set at 100 ml/min on a five-minute basis. Filters were changed before every 24 h to prevent filter saturation. During the sampling, the participants also completed a paper-and-pencil time-activity diary (TAD) every 15 min, recording their main indoor or outdoor activities, start and end time of each activity, and its location. The children were asked to record whether someone was cooking or smoking near them since these activities are known to be major BC sources. Questionnaires were answered by children's parents prior to the measurement in order to investigate personal characteristics, residential environment, and potential confounders. Follow-up interviews with the children and their parents or teachers allowed us to enhance the understanding of the activities the children actually executed or the locations they visited.

Table 1
Pearson's correlation coefficient (*r*) among the three personal peak concentration measures for the forty children.

Measure comparison	*r*
TWA vs. 95 pctl	0.8860
TWA vs. 99 pctl	0.1820
95 pctl vs. 99 pctl	0.3206
LN (TWA) vs. LN (95 pctl)	0.8974
LN (TWA) vs. LN (99 pctl)	0.2476
LN (95 pctl) vs. LN (99 pctl)	0.4625

Abbreviations: TWA, time-weighted average; LN, natural log transformed; pctl, percentile.
Note: Each peak concentration measure was calculated for every 24 h per child separately using five-minute data.