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Exploring variability in pedestrian exposure to fine particulates ($PM_{2.5}$) along a busy road

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Abstract

In August 2006, pedestrian exposure to $PM_{2.5}$ was monitored along a busy roadway in Sydney, Australia. The objective of the campaign was to assess the factors affecting exposure at both an inter- and intra-trip level. $PM_{2.5}$ measurements were made at second-by-second intervals using a portable aerosol monitor, while simultaneously recording location with a personal GPS device. A digital voice recorder was used to record any events or circumstances, perceived to notably increase potential $PM_{2.5}$ levels. The average $PM_{2.5}$ concentration for the 39 trips conducted was 12.8 $\mu g\,m^{-3}$, which while 40% higher than concurrent ambient measurements was well within proposed daily standards for Australia. Multivariate time-series methods were then applied to study the effects of various interventions on $PM_{2.5}$ at an intra-trip level while controlling for autocorrelation. Wind speed, traffic volumes and clearway operations (independent of traffic volumes) were found to be significant predictors in addition to the previous $PM_{2.5}$ concentrations. Sensitivity analysis showed doubling traffic volumes increased $PM_{2.5}$ concentrations by 26%, while each 5 $km\,h^{-1}$ increase in wind speed increased $PM_{2.5}$ concentrations by 10%. Several $PM_{2.5}$ hotspots were identified where concentrations exceeded 100 $\mu g\,m^{-3}$. These were attributed to specific traffic (intersections, trucks, buses) and non-traffic sources (pedestrians smoking), typically only lasting a few seconds.

Keywords: Pedestrian exposure; $PM_{2.5}$; Time-series methods; Personal monitoring; Sydney

1. Introduction

The connection between exposure to airborne particulate matter (PM) and adverse health consequences is under increasing scrutiny (Gong et al., 2007). Of focus recently have been the finer fractions, particularly those with an aerodynamic diameter of $<2.5\,\mu m$ ($PM_{2.5}$), because of their deeper penetration into the gas exchange region of the lung. This in turn has been associated with increasing the risk of lung cancer and other respiratory-related problems (Greaves, 2006). Although current regulatory standards for $PM_{2.5}$, shown together with standards for PM_{10} in Table 1, reflect a maximum concentration not to be exceeded over 1 day and 1 year, recent epidemiological evidence suggests peak exposures of 1 h or less may be more relevant from a health perspective (Michaels and Kleinman, 2000). The implications are that it has become important to know with greater precision the microenvironments in which higher levels of particulate concentrations occur and how long people spend in these

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Table 1
Current regulatory standards for fine particulate matter

Pollutant	Averaging times	Maximum concentration ($\mu g\,m^{-3}$)			EPHC goal for maximum allowable exceedences within 10 years in Australia
		Australia	US	Europe	
PM_{10}	Annual		Revoked	40	5 days a year
	24 h	50	150	50	
$PM_{2.5}$	Annual	8 (proposed)	15		Yet to be established
	24 h	25 (proposed)	35	25	

Source: Environmental Protection and Heritage Council (EPHC, http://www.ephc.gov.au) and US Environmental Protection Agency (EPA, http://www.epa.gov).

microenvironments (and therefore at risk of higher exposure) as they go about their daily lives.

Roadway microenvironments have received particular attention both because $PM_{2.5}$ concentrations are often substantially higher than ambient levels on which standards are assessed (Adams et al., 2001) and because people can spend significant amounts of time in such environments. In response, several experimental studies have been conducted to identify critical factors impacting $PM_{2.5}$ exposure while traveling—a summary of recent studies is provided by Kaur et al. (2007). Among their conclusions, the authors' note the relative paucity of information on pedestrian exposure. This is (perhaps) surprising given walking is something most of us do on a regular basis—for instance, 17% of trips in Sydney are made by walking—as a means to access destinations directly, to provide access and egress for other modes of transport or simply for recreation. In addition, with the growing impetus of policies and programs to incorporate walking into daily travel routines as a 'healthy' alternative to vehicular-based (Pucher and Dijkstra, 2003), it has become (arguably) even more important to understand how this might impact exposure to air pollution, particularly in the vicinity of traffic. Empirical evidence to date suggests while pedestrians may receive similar or lower $PM_{2.5}$ average concentrations compared to those inside vehicles (Gulliver and Briggs, 2004; Kaur et al., 2005), these levels invariably exceed ambient levels. In addition, there is evidence of great variability of exposure levels between and within trips including specific instances (hotspots) where levels are substantially elevated (Greaves, 2006).

This paper presents the results of a monitoring campaign of pedestrian exposure on a busy mixed-use arterial roadway in Sydney, which experiences high pedestrian and vehicle flows throughout the day. The aims of the campaign were to identify and assess the major factors affecting exposure at both an inter- and intra-trip level, including the identification of $PM_{2.5}$ hotspots attributed to traffic sources (e.g., intersections, particular vehicles) and non-traffic sources (e.g., other pedestrians smoking). Key to the analysis was a means to easily collect and reference the $PM_{2.5}$ information at highly disaggregate spatio-temporal levels of resolution while walking. This was facilitated using personal Global Positioning System (GPS) technology and portable aerosol monitors described in the next section.

2. Study area and data collection

The study focused on King Street and Missenden Road in the suburb of Newtown, located in Sydney's Inner West (Fig. 1). King Street is a major four-lane arterial famed for its vibrant mix of restaurants, cafes, and shops as well as providing a primary conduit from the south of Sydney to the Central Business District (CBD). It attracts high numbers of pedestrians throughout the day and night and experiences heavy traffic flows including a significant proportion of heavy goods vehicles. Missenden Road is also a four-lane arterial, which intersects with King Street. It provides access to one of Sydney's largest hospitals, the Royal Prince Alfred Hospital (RPAH), and points north. It is characterised by much lower traffic volumes than King Street, but has moderate pedestrian activity during the day, largely associated with accessing King Street.

The study route was designed as a circuit that started and ended at Newtown Station. It comprised the most representative part of King Street (shown