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Particulate matter exposure along designated bicycle routes in Vancouver, British Columbia

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ABSTRACT

An instrumented bicycle was used to elucidate particulate matter exposures along bicycle routes passing through a variety of land uses over 14 days during summer and fall in a mid-latitude traffic dominated urban setting. Overall, exposures were low or comparable to those found in studies elsewhere (mean $PM_{2.5}$ and PM_{10} concentrations over each daily bicycle traverse varied between 7–34 μg m^{-3} and 26–77 μg m^{-3} respectively). Meteorological factors were responsible for significant day-to-day variability with $PM_{2.5}$ positively correlated with air temperature, PM_{10} negatively correlated with precipitation, and ultrafine particles negatively correlated with both air temperature and wind speed. On individual days, land use and proximity to traffic were factors significantly affecting exposure along designated bicycle routes. While concentrations of $PM_{2.5}$ were found to be relatively spatially uniform over the length of the study route, PM_{10} showed a more heterogeneous spatial distribution. Specifically, construction sites and areas susceptible to the suspension of road dust have higher concentrations of coarse particles. Ultrafine particles were also heterogeneously distributed in space, with areas with heavy traffic volumes having the highest concentrations. Observations show qualitative agreement in terms of spatial patterns with a land-use regression (LUR) model for annual $PM_{2.5}$ concentrations.

1. Introduction

In many cities, cycling is promoted as a healthy alternative to vehicular commuting that reduces traffic congestion, reduces emissions of air pollutants and greenhouse gases, and increases human physical activity. However, relatively few studies have investigated exposure of cyclists to atmospheric pollutants as they pass through a variety of urban micro-environments. From a health perspective, studies assessing cyclists' exposures to particulate matter (PM) are especially important as urban concentrations of PM have been linked to a broad array of health impacts, including cardiopulmonary morbidity and mortality (Pope and Dockery, 2006). Recent studies have also raised the possibility of enhanced toxicity associated with exposure to ultrafine particles, especially those produced in motor vehicle exhaust (Delfino et al., 2005; Zhou and Levy, 2007).

The majority of published studies dealing with cyclists' exposure to PM have been conducted in Europe (Table 1) and only Bevan et al. (1991) has focused exclusively on cyclists. Most of these studies compared cyclists' exposure to that of other modes of transportation such as cars (Adams et al., 2001b; Rank et al., 2001), buses (Gee and Raper, 1999; Adams et al., 2001b), and the subway (Adams et al., 2001b). Generally, previous studies have demonstrated that cyclists' personal exposure levels to PM is considerably lower than levels measured in cars or buses (Gee and Raper, 1999; Adams et al., 2001b; Rank et al., 2001). A possible reason for lower exposure is that cyclists often travel beside

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Table 1 – Summary of previous studies addressing cyclists' personal exposure to particulate matter

Authors	Location	Particle size measured	Mean ($\mu g\ m^{-3}$)	Minimum ($\mu g\ m^{-3}$)	Maximum ($\mu g\ m^{-3}$)
Bevan et al. (1991)	Southampton, UK	Respirable suspended particulates (RSP)	130	–	–
Gee and Raper (1999)	Manchester, UK	PM_4	54	16.8	122
Adams et al. (2001b)	London, UK	$PM_{2.5}$	34.5 (summer) 23.5 (winter)	13.3 (summer) 6.8 (winter)	68.7 (summer) 76.2 (winter)
Rank et al. (2001)	Copenhagen, DK	Total dust	44	21	68
Vinzents et al. (2005)	Copenhagen, DK	Ultrafine particles	32400 Pt/mL	–	–

traffic rather than behind, reducing the amount of direct exposure to vehicle exhaust (Gee and Raper, 1999). Furthermore, in congested traffic conditions, cyclists are able to avoid becoming trapped behind slow-moving or idling vehicles, reducing their time in a congested and polluted environment, thus reducing their exposure to particulate matter (Adams et al., 2001b; Gee and Raper, 1999). Despite a breathing rate of cyclists that is 2.3 times higher than that for occupants of motor vehicles (van Wijnen et al., 1995), Adams et al. (2001b) and Rank et al. (2001) were still able to show that cyclists' intake of pollutants was lower than that of drivers. Again, this can likely be explained by the fact that cyclists are able to bypass traffic congestion to reduce exposures. Only one study to date has reported on cyclist exposures to ultrafine particles (Vinzents et al., 2005). That study noted exposures that were correlated with concentrations of carbon monoxide and slightly higher than those measured at an outdoor fixed monitoring site, suggesting traffic as a major source of ultrafine particle exposure.

In this study, research conducted in European cities is extended to the North American context (Vancouver, BC), and focuses on cyclists' PM (including ultrafine PM) exposure along designated bicycle routes passing through a variety of urban microenvironments. We were especially interested in assessing whether exposures on designated bicycle routes located away from main vehicle traffic corridors were lower than those on routes adjacent to high traffic roads. As such, we present an observational extension of the modelling study conducted by Hertel et al. (2008) for Copenhagen in which the Operational Street Pollution Model suggested that judicious route selection through the urban environment may significantly reduce pollutant exposure. A novel instrumented bicycle with GPS is used to continuously measure exposure to PM in size fractions ranging from the ultrafine (<0.1 μm in diameter) to coarse particles along a ~20-km designated bicycle route ridden on 14 separate days during morning rush hour (7–9 am) over a three-month period (August to October). Although particle size distributions in 15 size classes were measured, the most commonly used metrics (i.e. PM_{10}, $PM_{2.5}$ and "ultrafine" particles) were calculated to facilitate comparison to standards and other studies. Primary objectives of this study are:

- Determine size distributed PM exposure along designated bicycle routes
- Explore the influence of mesoscale meteorological factors on exposure
- Identify portions of routes or land uses where exposure is greatest
- Compare results with a land-use regression (LUR) model of traffic induced $PM_{2.5}$ (Henderson et al., 2007).

In so doing, it is intended that such information will assist cyclists as they weigh the risks of bicycle commuting, and by planners as they seek the optimal design of designated bicycle networks.

2. Methods

2.1. *Background*

Vancouver (49.5°N, 123°W), is a coastal city comprising part of a larger metropolitan area with a population of close to two million inhabitants. With a west coast location, few industrial or solid fuel home heating sources, and abundant winter rainfall, PM concentrations are relatively low compared to many industrialised mid-latitude cities (Vedal et al., 2003). Mean annual PM_{10} concentrations are ~15 $\mu g\ m^{-3}$ with maximum hourly values reaching ~50 $\mu g\ m^{-3}$ during periods of reduced dispersion primarily during occasional summer photochemical smog events (McKendry, 2000). The city is home to an avid cycling community, and boasts an extensive network of bicycle routes. These routes are primarily residential side streets with modifications for cyclists, such as traffic signal push buttons closer to the road, pavements markings, and directional signs. Other bicycle routes are in the form of designated cycling lanes on major roads, or off-road trails. The bicycle route chosen for this study is shown in Fig. 1 and incorporates a wide range of microenvironments ranging from off-road sea side routes, to residential neighbourhoods and major arterial routeways through the central business district. The route also includes major bridges and passes by areas of construction.

2.2. *Instrumentation*

Two instruments were mounted on a bicycle in order to continuously measure PM concentrations. Firstly, a *GRIMM* 1.108 ("Dustcheck" — Series 1.108 (GRIMM Labortechnik Ltd., 1996)) was used to measure PM ranging from 0.3 to 20 μm in diameter. The *GRIMM* is an optical particle counter (based on the principle of light scattering) and provides particle counts in 15 size categories at six-second resolution. These data may be converted to a volume distribution (based on the PM diameter and assuming spherical particles) or a mass