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Exposure assessment of a cyclist to PM_{10} and ultrafine particles

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ABSTRACT

Estimating personal exposure to air pollution is a crucial component in identifying high-risk populations and situations. It will enable policy makers to determine efficient control strategies. Cycling is again becoming a favorite mode of transport both in developing and in developed countries due to increasing traffic congestion and environmental concerns. In Europe, it is also seen as a healthy sports activity. However, due to high levels of hazardous pollutants in the present day road microenvironment the cyclist might be at a higher health risk due to higher breathing rate and proximity to the vehicular exhaust.

In this paper we present estimates of the exposure of a cyclist to particles of various size fractions including ultrafine particles (UFP) in the town of Mol (Flanders, Belgium). The results indicate relatively higher UFP concentration exposure during morning office hours and moderate UFP levels during afternoon. The major sources of UFP and PM_{10} were identified, which are vehicular emission and construction activities, respectively. We also present a dust mapping technique which can be a useful tool for town planners and local policy makers.

1. Introduction

Epidemiological studies worldwide have consistently demonstrated links between ambient particulate matter exposure and adverse health outcomes, including increased rates of respiratory and cardiovascular illness, hospitalizations, and pre-mature mortality (Pope and Dockery, 2006; Nawrot et al., 2007). Particles are usually defined by their size, e.g., PM_{10} and $PM_{2.5}$, as the mass of particles with aerodynamic diameters less than 10 to 2.5 μm, respectively. Recently, however, interest has also focused on the fraction of ultrafine particles (UFP) with a diameter less than 0.1 μm, which are abundant in number but contribute little to the mass (Donaldson et al., 1998; Penttinen et al., 2001).

Studies have shown that ultrafine particles are more toxic than larger particles (Wahlin et al., 2001; Donaldson et al., 2002; Li et al., 2003; Pietropaoli et al., 2004). Furthermore, individual particles have been shown to be capable of inducing inflammation and oxidative stress (Li et al., 2003), suggesting that particle number concentrations, which are dominated by ultrafine particles, may be more indicative of some potential health impacts than particle mass concentrations. UFP are also important because of their high alveolar deposition fraction, large surface area, ability to induce inflammation, and potential to translocate into the blood circulation system. At a given mass, ultrafine particles (diameter <0.1 μm) have 10^2 to 10^3 times more surface area than particles with diameters in the 0.1–2.5 μm range and approximately 10^5 times more surface area than coarse particles (2.5 μm <diameter <10 μm) (Harrison et al., 2000). This surface area-to-mass effect may affect the relative toxicity of particles to respiratory systems, in combination with a higher deposition efficiency of ultra fines in the alveolar region (Hughes et al., 1998).

In recent years UFP research is concentrated on the following hypotheses which have been reviewed previously

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(Donaldson et al., 2002; Kreyling et al., 2004). Ultrafine particles:

- have a high specific surface area, which can catalyse reactions and adsorb high amounts of toxic substances (like PAH), providing a carrier deep into the lung during inhalation (Seaton et al., 1995);
- have a higher deposition probability particularly in small airways and the alveolar region of the lungs than fine particles (Donaldson et al., 1998);
- are less well phagocytized by alveolar macrophages than larger particles and inhibit their phagocytic ability (Lundborg et al., 2001);
- are taken up by other cells of the respiratory epithelium, such as epithelial cells, dendritic cells (Ferin et al., 1992; Müller et al., 2004);
- may form complexes with proteins and biomolecules which may result in functional changes of the latter (Borm and Kreyling, 2004);
- have greater access to interstitial spaces than larger particles (Stearns et al., 2001; Oberdörster et al., 2002);
- have access to the blood circulation (Nemmar et al., 2002; Oberdörster et al., 2002; Kreyling et al., 2002);
- induce more oxidative stress than fine particles (Li et al., 2003; Stone et al., 2000);
- cause more pro-inflammatory responses than larger particles (Donaldson et al., 2001, 2002);
- adversely affect cardiac functions and vascular homeostasis (Stone and Godleski, 1999);
- affect immunity (Kreyling et al, 2004).

For all of these hypotheses there exists a growing body of studies on a mechanistic level providing plausibility or evidence, however, on different levels of causality. From many of these studies it became also clear that the hypotheses listed above may only be applicable to susceptible organisms and individuals predisposed either by disease, genetics or age while the healthy organism does not show any such sensitive reactions.

Hence, researchers worldwide have paid increasing attention to ultrafine particles in the atmosphere, and specifically from vehicular emissions, focusing on the number concentration of ultrafine particles (Hughes et al., 1998; Hitchins et al., 2000; Shi et al., 2001; Kittelson et al., 2004).

In urban environments the dominant sources of ultrafine particles are direct emissions from motor vehicles and secondary particles generated by the photochemical or physical processes in the atmosphere (Fine et al., 2004; Zhang et al., 2004a). Most of the PM emissions (and related health impacts) are attributed to diesel fueled vehicles (Int Panis et al., 2001, 2004, 2006). Vehicles may generate exhaust particles with diameters in the 10–300-nm range, with an average of about 60 nm (Maricq et al., 1999). Kittelson et al. (2004) also indicated that most particles emitted by on-road vehicles had diameters of below 50 nm. Recent studies have found that atmospheric dispersion, dilution, condensation/evaporation, coagulation, and deposition influence the particle number concentration and size distribution (6–220 nm) with distance away from the freeways (Zhu et al., 2002; Zhang et al., 2004b; Zhu and Hinds, 2005), and the indoor environments near freeways may experience significant concentrations of outdoor ultrafine particles from freeways (Zhu and Hinds, 2005; Kuhn et al., 2005).

Exposure in the urban transport microenvironment or close to streets is of particular concern because many people spend part of their time in this microenvironment, and because here exposures to pollutants are often highly elevated in comparison to elsewhere (Brunekreef et al., 1997). In addition, there is an association between exposure to traffic and adverse health outcomes (Peters et al., 2004).

This consequently highlights the need for personal exposure measurements while participating in traffic. Recent technological advances now make this possible and also permit the measurement of sub micrometer particulates (Donaldson et al., 2001, 2002). A sufficiently high-resolution understanding of people's exposures to harmful pollutants, such as UFP, during daily activities in different microenvironments is necessary to protect and promote public health (Wagener et al., 1995). Simultaneous information related to exposure, such as the time, duration, location, magnitude of exposure is crucial to assess environmental health risks and for making informed decisions to manage and reduce the risk. To address this issue, we have adapted the use of shorter time resolution instrumentation which has already been used in conjunction with video exposure monitoring and has proven to be an effective communication tool in the workplace environment (McGlothlin, 2005; Rosèn et al., 2005; Kaur et al., 2006).

In this study, levels of particles were monitored in the cyclist's breathing zone. An experimental method to measure the exposure of a cyclist to different size fractions of PM including UFP, at a high resolution with the help of GPS, GIS and video images is presented. The purpose of this paper is not only to explain the exposures obtained, but also, to demonstrate and evaluate the exposure visualization technique as a valuable tool allowing exposure patterns and peaks that are often ignored/missed in quantitative analysis to be considered, as a complement to the traditional approaches. In an ongoing study measured PM concentrations will be combined with simultaneous recordings of breathing activity (Int Panis et al., in preparation).

2. Experimental method

2.1. *Instrumentation*

In the present study a bicycle equipped with a number of different assembled instrumentations (collectively called as the AeroFlex II) was used, which can give size resolved aerosol concentrations in the ambient environment. The AeroFlex II system is a useful tool for evaluating and demonstrating personal exposure. It captures the time-activity exposure patterns of individuals in an urban transport microenvironment. It consists of 4 different instruments: a GRIMM 1.108 Dust monitor, a TSI P-TRAK, a commercial GPS and a video camera. The GRIMM 1.108 spectrometer is a portable environment dust monitor which can simultaneously measure $PM_{1.0}$, $PM_{2.5}$, PM_{10} and TSP (Colls and Micallef, 1999; Junker and Monn, 1998; Querol et al., 2001). It has two optical sensors