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Review

Assessment of personal exposure to particulate air pollution during commuting in European cities—Recommendations and policy implications

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HIGHLIGHTS

- Car commuter's exposure depends on traffic intensity and emissions by nearby vehicles
- Cyclists are exposed to lower PM levels in comparison to those inside vehicles
- Renovation of public vehicles will reduce commuter's exposure

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ABSTRACT

Commuting is considered as one of the high-exposure periods among various daily activities, especially in high vehicle-density metropolitan areas. There is a growing awareness of the need to change our transportation habits by reducing our use of cars and shifting instead to active transport, i.e. walking or cycling. A review was undertaken using the ISI web of knowledge database with the objective to better understand personal exposure during commuting by different modes of transport, and to suggest potential strategies to minimise exposure. The air pollutants studied include particulate matter, PM black carbon, BC and particle number concentration. We focused only in European studies in order to have comparable situation in terms of vehicle fleet and policy regulations applied. Studies on personal exposure to air pollutants during car commuting are more numerous than those dealing with other types of transport, and typically conclude by emphasising that travelling by car involves exposure to relatively high particulate matter, PM exposure concentrations. Thus, compared to other transport methods, travelling by car has been shown to involve exposure both to higher PM and BC as compared with cycling. Widespread dependence on private car transport has produced a significant daily health threat to the urban commuter. However, a forward-looking, integrated transport policy, involving the phased renovation of existing public vehicles and the withdrawal of the more polluting private vehicles, combined with incentives to use public transport and the encouragement of commuter physical exercise, would reduce commuters' exposure.

Contents

1. Introduction . . . 786
2. Materials and methods . . . 786
2.1. Study identification and selection . . . 786
2.1.1. Air pollutants studied . . . 786
3. Results and discussion . . . 787
3.1. Exposure during cycling . . . 787
3.2. Exposure in cars . . . 787
3.3. Exposure in buses . . . 787

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3.4. Exposure in underground train systems . . . 793
3.5. Comparison studies . . . 793
3.6. Other parameters investigated than transport mode . . . 794
3.6.1. Traffic conditions and route . . . 794
3.6.2. Travel speed . . . 794
3.6.3. Between-vehicle distance . . . 795
3.6.4. Ventilation . . . 795
3.6.5. Fuel type . . . 795
3.6.6. Meteorological conditions . . . 795
3.6.7. Other compounds studied . . . 795
4. Conclusions and recommendations . . . 795
Acknowledgements . . . 796
References . . . 796

1. Introduction

The association between traffic-related air pollution and health is becoming well established and documented from both epidemiological and toxicological studies (WHO, 2005, 2013). Exposure to particulate matter, PM can cause respiratory diseases, trigger cardiovascular morbidity and mortality after long-term and short-term periods (Anderson et al., 2012). Black carbon, BC is considered to be a better indicator of harmful particulate substances from combustion sources (especially traffic) than undifferentiated PM mass (Janssen et al., 2012) and is strongly associated with health outcomes in epidemiological studies (Heal et al., 2012). Another parameter that has drawn the attention of the research community due to its association with adverse health effects is the ultrafine particle UFP number concentration. Toxicological and laboratory studies have demonstrated cardiovascular and respiratory health effects of UFP, which likely have different and partly independent effects from larger particles, due to their small size, large surface area, different chemical composition and ability to penetrate deep into the alveolar system (Hoek et al., 2010).

Commuting is considered as one of the high-exposure periods among various daily activities, especially in high vehicle-density metropolitan areas (Duci et al., 2003). The report from the World Health Organization on the health effects of traffic-related air pollution points out that people spend 1–1.5 h/day commuting in many countries (WHO, 2005). Furthermore the levels of most air pollutants are particularly high along busy roads, common in urban transport environments and their concentrations peak during morning commute hours (Morawska et al., 2008; Moreno et al., 2009). As pollutants concentration are often elevated in the traffic microenvironment, individuals may gain a significant contribution to their daily exposure when commuting in traffic even though such individuals usually travel for no more than 6–8% time of the day (Kaur et al., 2007). This is confirmed by many studies demonstrating that commuting accounts for high contributions in total personal exposure. Indeed, during their regular journeys commuters can receive up to 30% of their inhaled daily dose of BC, and approximately 12% of their daily $PM_{2.5}$ personal exposure, (Dons et al., 2011, 2012; Fondelli et al., 2008).

In addition to decreasing emissions and keep on the efforts to decrease concentrations, one potential solution would be to reduce personal exposure by managing the actual exposure. The primary aim of this paper is to review the studies performed to date in order to better understand exposure to key air pollutants (PM, BC and UFP) during commuting by different modes of transport, and to suggest potential strategies to minimise personal exposure. UFP typically constitute 90% or more of particle number concentrations in areas influenced by traffic emissions (Morawska et al., 2008) thus in this paper we use particle number concentrations to describe UFP. We focus only in European studies in order to have comparable situation in terms of vehicle fleet and policy regulations applied. For example large shifts to diesel fuels in European cities in the last decade are considered to be a cause of stable (not lower) PM_{10} levels in European cities and no decline in the health impacts of air pollution — despite the introduction of cleaner diesel technologies (WHO, 2005). As most of the population in Europe lives in urban areas (73% according to the United Nations, World Urbanization Prospects, 2011 Revision) the studies examined have concentrated on the urban scale, although it is also important to take into account the exposure of the population living in more rural areas.

The commuting modes that we selected include car, bus, bicycling, and subway. Exposure during walking was not examined as this transport mode is mainly used for short trips or is part of other transport modes e.g.: combination of public transport with walking to transit stations. We note that dose assessment which is a complementary yet distinct concept to that of exposure is not the focus of this review. In the present study we do not examine the inhaled dose of pollutants during commuting due to the lack of studies determining it and also its complexity of interacting factors such as breathing rate, ventilation and/or particle deposition to the respiratory system.

2. Materials and methods

2.1. Study identification and selection

An electronic search on the ISI web of knowledge database and Google Scholar was conducted using various combinations: “air pollutants”, “black carbon”, “elemental carbon”, “ultrafine particle”, “transport mode”, “commuter”, “exposure” “public transport”, “microenvironment”, “vehicle”, “car”, “automobile”, “bus”, “cyclist”, “bicycle”, “underground system”, “metro”, “subway” without restrictions of publication type or publication date. The reference lists of studies identified by this method were reviewed for links to additional literature. In addition recent articles in relevant journals were collected. Only the studies concerning exposure measurements conducted in Europe are included in this paper. We present the results of the exposure studies performed across 4 transport modes: car, bicycle, bus, and subway focused solely on PM, EC or BC and particle number concentrations.

2.1.1. Air pollutants studied

The main air pollutants that have been determined in different commuting environments include:

- *PM mass concentrations* (Aarnio et al., 2005; Adams et al., 2001a, 2002; Alm et al., 1999; Asmi et al., 2009; Berghmans et al., 2009; Boogaard et al., 2009; Boudet et al., 1998; Braniš et al., 2006; Briggs et al., 2008; Colombi et al., 2013; de Nazelle et al., 2012; Dennekamp et al., 2002; Diapouli et al., 2008; Fondelli et al., 2008; Gee et al., 1999; Gee and Raper, 1999; Geiss et al., 2010; Gulliver and Briggs, 2007; Int Panis et al., 2010; Jacobs et al., 2010; Johansson and Johansson, 2003; Kingham et al., 1998; McNabola et al., 2008; Molle et al., 2013; Querol et al., 2012; Raut et al., 2009; Ripanucci et al., 2006; Salma et al., 2007; Seaton et al., 2005; Strak et al., 2010; Pfeifer et al., 1999; Rank et al., 2001; Zuurbier et al., 2010).
- *Black carbon, BC or elemental carbon, EC* (Adams et al., 2002; de Nazelle et al., 2012; Dons et al., 2012, 2013; Fromme et al., 1998; Le Moulle et al., 1998).