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Particulates and noise exposure during bicycle, bus and car commuting: A study in three European cities

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ABSTRACT

Background: In order to curb traffic-related air pollution and its impact on the physical environment, contemporary city commuters are encouraged to shift from private car use to active or public transport modes. However, personal exposures to particulate matter (PM), black carbon and noise during commuting may be substantial. Therefore, studies comparing exposures during recommended modes of transport versus car trips are needed.
Methods: We measured personal exposure to various-sized particulates, soot, and noise during commuting by bicycle, bus and car in three European cities: Helsinki in Finland, Rotterdam in the Netherlands and Thessaloniki in Greece using portable monitoring devices. We monitored commonly travelled routes in these cities.
Results: The total number of one-way trips yielding data on any of the measured parameters were 84, 72, 94 and 69 for bicycle, bus, closed-window car and open-window car modes, respectively. The highest mean $PM_{2.5}$ (85 μg/m^3), PM_{10} (131 μg/m^3), black carbon (10.9 μg/m^3) and noise (75 dBA) levels were recorded on the bus, bus (again), open-window car and bicycle modes, respectively, all in Thessaloniki, PM and soot concentrations were generally higher during biking and taking a bus than during a drive in a a car with closed windows. Ratios of bike:car PM_{10} ranged from 1.1 in Thessaloniki to 2.6 in Helsinki, while bus:car ratios ranged from in 1.0 in Rotterdam to 5.6 in Thessaloniki. Higher noise levels were mostly recorded during bicycle rides.
Conclusion: Based on our study, active- and public-transport commuters are often at risk of higher air pollution and noise exposure than private car users. This should be taken into account in urban transportation planning.

1. Introduction

Road traffic is a major source of particulate matter (PM) air pollution in urban areas (Knibbs et al., 2011; Morawska et al., 2008). Although small proportions of daily time are routinely spent on intra-city transit, a commuter may incur substantial exposures to particulates within these intervals (Dons et al., 2011). Physically more active modes of transportation result in raised respiratory rate, consequently inducing higher intakes of PM (de Nazelle et al., 2012; Dons et al., 2012).

Particulates are commonly characterised according to their size differentiation and chemical composition. Particles with aerodynamic diameter below 2.5 μm ($PM_{2.5}$) are known as fine particles, PM_{10} are particles with diameter < 10 μm (World Health Organization, 2006; World Health Organization, 2013). Mass concentrations are typically used to monitor these size fractions. Coarse particles concentration ($PM_{2.5-10}$) is obtained by subtracting $PM_{2.5}$ from PM_{10} (World Health Organization, 2006), while the particle number concentration (PNC) is the total number of particles per unit volume of air (ISO 27891, 2015). About 90% of the PNC consists of ultra-fine particles (diameter

Abbreviations: AMI, Acute Myocardial Infarction; ANC, Active Noise Control; BC, Black carbon; CWC, Closed-window car; dBA, A-weighted Decibels; HEL, Helsinki; OWC, Open-window car; PM, Particulate Matter; $PM_{2.5}$, Particulate matter less than 2.5 micrometres; PM_{10}, Particulate matter less than 10 micrometres; $PM_{2.5-10}$, Particulate Matter with diameter between 2.5 and 10 micrometres; PNC, Particle number concentration; pp, Particles; ROT, Rotterdam; THE, Thessaloniki; UFP, Ultrafine particles; µg, Micrometre; µg/m^3, Microgram per cubic metre

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between 0.1 and 0.001 μm) (Morawska et al., 2008; World Health Organization, 2006) which, incidentally, contribute very little to the mass concentration (Ruuskanen et al., 2001). Black carbon is a bi-product of incomplete combustion of hydrocarbon fuels. It's light absorbing, typically 0.1 μm at emission and is a marker of adverse health effects of airborne particles (Janssen et al., 2011; World Health Organization, 2012). Epidemiological studies have associated finer particulate fractions with cardiovascular and respiratory diseases (Brunekreef and Holgate, 2002; Knibbs et al., 2011).

The mode of transportation is an important determinant of commuter exposure (de Nazelle et al., 2012). However, there is no consensus on which transportation mode is prone to higher commuter PM exposure (Int Panis et al., 2010). While some studies have recorded higher PM exposures in cars compared to buses(Boogaard et al., 2009) or bicycles (Adams et al., 2001), others have found higher exposures during bicycling (Int Panis et al., 2010). Disparities in study protocols, vehicle features, seasons and daily periods selected for measurements may explain inconsistency of findings (Kingham et al., 2013) as well as differences in differences in car (or bus) window position and ventilation settings.

Road traffic is the most important source of community noise (Paunović et al., 2009; Kono and Sone, 1988). Road traffic-related noise arises from the same source as primary urban PM (Vlachokostas et al., 2012); nonetheless, traffic-related noise and PM are typically not studied together (Davies et al., 2009), thereby limiting our understanding of variations in shared exposure to these pollutants.

The majority of motorised vehicles are private cars. Policies which aim to limit the volume of motorised traffic—by targeting a reduction in private car use while promoting movement by mass-transit systems and active modes—are justified in the strive for environmental sustainability, but public health implications are equally important. Policies should, however, be shaped by scientific evidence. It is, therefore, pertinent to characterise commuter-in-transit exposures by typical urban modes of transportation. Cross-border similarities in patterns of exposure may lend support to or provide basis for modification of existing theories of mode-specific exposures. This study describes and compares exposures to $PM_{2.5}$, PM_{10}, $PM_{2.5\text{-}10}$, PNC, black carbon and noise during commute by three modes of transportation in three European cities.

2. Materials and methods

2.1. Study cities and design

Exposure measurements were conducted in Helsinki, Finland; Rotterdam, the Netherlands; and Thessaloniki, Greece, located in northern, central and southern Europe, respectively. In each city, PM concentrations and A-weighted noise levels were measured on much used daily-transit routes during car trips, and simultaneously on either a bus or a bicycle. In order to maximise comparability, standardised methods were used for all measurements in spring and early summer of the year 2011, specifically: 5th to 13th of April in Thessaloniki; 10th to 19th of May in Rotterdam; and 7th to 17th of June in Helsinki. The locations of these cities are illustrated in Fig. 1. In each city, two to six busy commuting routes were selected based on knowledge of local researchers and/or environmental authorities on the commuting behaviour in the cities. The same routes, each measuring approximately 8 km, were used by all transport modes.

Helsinki is the capital city of Finland. The metropolitan Helsinki area has a population of approximately 1 million. It is situated on a narrow cape facing south toward the Gulf of Finland. The city has a complex geometry which incorporates several islands. Six routes were

Fig. 1. Location of study cities. Basemap: ©2013 Esri, DeLorme, NAVTEQ.