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Urban air quality comparison for bus, tram, subway and pedestrian commutes in Barcelona

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ABSTRACT

Access to detailed comparisons in air quality variations encountered when commuting through a city offers the urban traveller more informed choice on how to minimise personal exposure to inhalable pollutants. In this study we report on an experiment designed to compare atmospheric contaminants inhaled during bus, subway train, tram and walking journeys through the city of Barcelona. Average number concentrations of particles 10-300 nm in size, *N*, are lowest in the commute using subway trains ($N < 2.5 \times 10^4$ part. cm^{-3}), higher during tram travel and suburban walking (2.5×10^4 cm$^{-3} < N < 5.0 \times 10^4$ cm^{-3}), and highest in diesel bus or walking in the city centre ($N > 5.0 \times 10^4$ cm^{-3}), with extreme transient peaks at busy traffic crossings commonly exceeding 1.0×10^5 cm^{-3} and accompanied by peaks in Black Carbon and CO. Subway particles are coarser (mode 90 nm) than in buses, trams or outdoors (< 70 nm), and concentrations of fine particulate matter ($PM_{2.5}$) and Black Carbon are lower in the tram when compared to both bus and subway. CO_2 levels in public transport reflect passenger numbers, more than tripling from outdoor levels to > 1200 ppm in crowded buses and trains. There are also striking differences in inhalable particle chemistry depending on the route chosen, ranging from aluminosiliceous at roadsides and near pavement works, ferruginous with enhanced Mn, Co, Zn, Sr and Ba in the subway environment, and higher levels of Sb and Cu inside the bus. We graphically display such chemical variations using a ternary diagram to emphasise how “air quality” in the city involves a consideration of both physical and chemical parameters, and is not simply a question of measuring particle number or mass.

1. Introduction

Most modern cities have serious environmental issues linked to pervasive airborne particle emissions from road traffic and other anthropogenic sources. The resulting effect on urban human health depends on a complex mix of factors that includes airborne particle concentration, size, and composition, the distribution of pollutants in time and space, and the physical condition of the urban traveller. Given this inherent complexity, and a corresponding lack of consensus among researchers as to which PM characteristics most closely relate to health effects, the simple act of measuring average pollutant concentrations at background monitoring stations or traffic hot-spots (especially in the case of ultrafine particles) offers only a general guide to actual variations in airborne particle concentrations and compositions inhaled by people moving through the city (Kaur et al., 2007; Zuurbier et al., 2010; de Nazelle et al., 2012). This is of particular relevance to regular commuters, who will receive a widely differing dose of air

Abbreviations: PM2.5, particulate matter with a diameter below 2.5 microns; PEM, Personal Environmental Monitor; ICP-AES, Inductively Coupled Plasma Atomic Emission Spectroscopy; ICP-MS, Inductively Coupled Plasma Mass Spectrometry; CPC, condensation particle counter; *N*, particle number concentrations; BC, Black Carbon; SCRT®, Selective Catalytic Reduction+Continuously Regenerating Trap; ADSA, alveolar deposited surface area

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pollutants depending on the mode of transport/microenvironment they select to get to and from work and the area of the city where they commute.

Previous publications have identified many of the influences on the distribution of transport-related air pollutants in the city environment (e.g. Adams et al., 2001; Hammond et al., 2006; Kaur et al., 2006, 2007; Kaur and Nieuwenhuijsen, 2009; Moreno et al., 2009; Zuurbier et al., 2010; Knibbs et al., 2011; de Nazelle et al., 2012; Kingham et al., 2013; Karanasiou et al., 2014; Gu et al., 2015; Liu et al 2015). Levels of particulate mass will depend on such factors as traffic intensity (Zhu et al., 2002; Buonanno et al., 2011), time of the day (Kaur et al., 2007; Dons et al., 2011; de Nazelle et al., 2012), meteorology (Gomez-Perales et al., 2004; Kaur et al., 2007; Buonanno et al., 2011), type of vehicles (Dons et al., 2011), and distance to the road (Kaur et al., 2006, 2007). In terms of particle number (*N*), most inhalable traffic particles fall into the ultrafine size range (particles with a diameter less than 100 nm) (Morawska et al., 2008), with diesel buses providing an especially potent pollutant source (Kaur et al., 2007; Knibbs and de Dear, 2010; Kingham et al., 2013) and comparing unfavourably with, for example, gas- or electric powered buses (Zuurbier et al., 2010; Dons et al., 2011; Ragettli et al., 2013). Indoor controls such as the use of strong ventilation in subway platforms (Querol et al., 2012) or air conditioning in underground trains can have a clearly beneficial effect (Martins et al., 2015a). In addition to Particulate Matter (PM) distribution, CO levels provide another marker for vehicle exhaust emissions in the urban environment, with typically higher concentrations breathed when travelling by car (Kingham et al., 2013) or bus (Kaur et al., 2007; de Nazelle et al., 2012) compared to walking.

In this paper we offer further insight into the reality of variations in urban air quality experienced during travel on different forms of public transport, and compare these to conditions while walking in the city. Our study uses continuously measuring portable equipments carried by two commuters making journeys through the city with the same start and end point and at the same time but using different transport modes (bus, subway, tram and walking). The study continuously tracks and compares not only PM mass and N during each journey, but also Black Carbon, Carbon Monoxide, Carbon Dioxide and, as far as we are aware, for the first time includes chemical composition of the finer material inhaled ($PM_{2.5}$) by individuals whilst moving through the city.

2. Methodology and working conditions

The monitoring equipment was carried in backpacks by two commuters during October and November 2014, each separately and simultaneously making a round trip route (carrying a GPS) using one of the four selected transport modes in the city of Barcelona for a total of 39 weekdays, with only one day with rain. The commuter pairs began their journey together but took different routes through the city. The commute chosen was 8.4–9 km long (4.2–4.5 km each way depending on the transport mode) from the suburban area of the IDAEA-CSIC Institute in Pedralbes to the Diagonal metro stop on La Rambla in the city centre (Fig. 1). Four types of commute were included in the study: walking only, walking + tram, bus, and subway train (Metro).

Walking only: The pedestrian-only route followed the sidewalks of the Diagonal Avenue, a straight multilane urban highway that provides a key arterial entry and exit route for the city. Despite the heavy traffic along this highway (132,000 vehicles per day), it is used by many pedestrians and cyclists. There is a clear division between the suburban and city centre sectors of this highway, demarcated around halfway into the journey by the Francesc Macia roundabout (Fig. 1). Whereas the suburban sector (west side) is open and with generally wide sidewalks (100 m wide), the city centre sector is more severely congested, more narrow (45 m) and canyon-like and with a higher number of crossroads. At the time of our monitoring experiment a major restructuring of this central part of the Diagonal was taking place, involving extensive repaving and associated uncontrolled emissions under dry conditions, providing us with an interesting opportunity to highlight the effect of such works (which are not uncommon in the city) on air quality. The same route was followed each day, with the outward journey along the northern side of the Diagonal, and the return journey being made on the opposite side.

Walking + tram: Because of the special conditions produced by

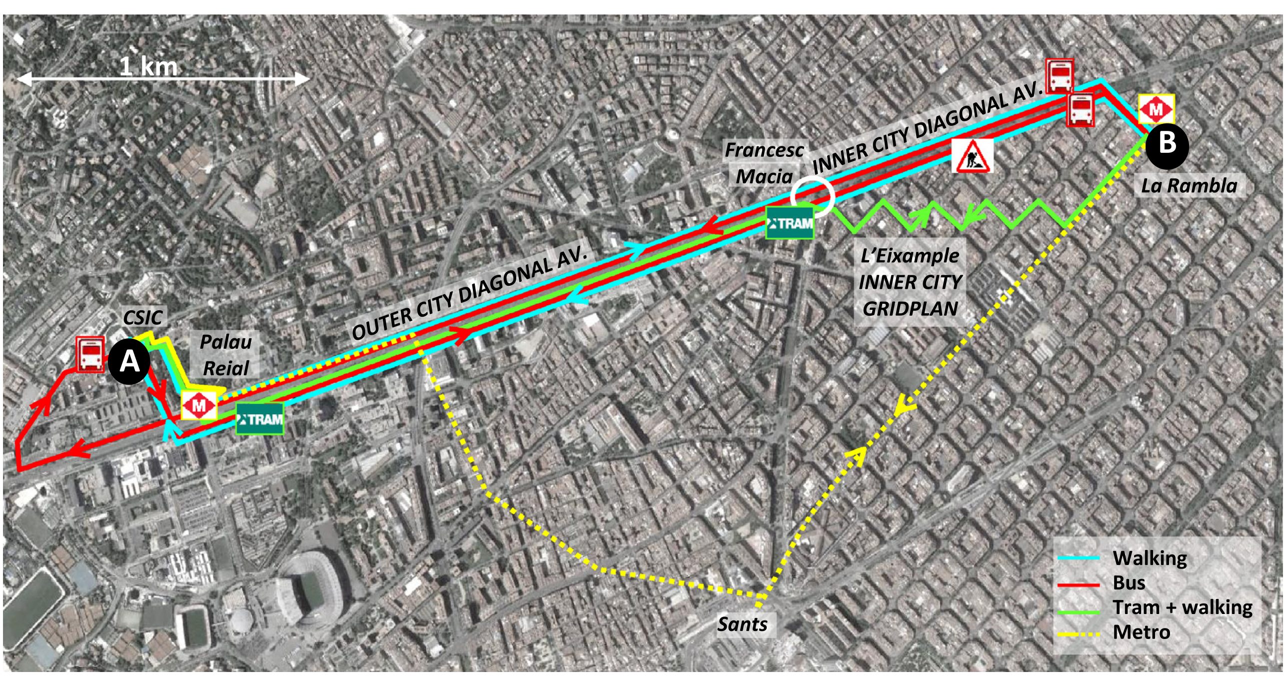

Fig. 1. Selected routes for measuring air quality while walking and travelling by bus, tram and metro. The figure shows the locations of the beginning (A, CSIC) and final (B, La Rambla) point of the route, the tram, bus and metro stops and the area with important street works.