Atmospheric Environment 61 (2012) 197–203

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Inhaled particle counts on bicycle commute routes of low and high proximity to motorised traffic

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HIGHLIGHTS

► We identify popular bicycle commute routes of Brisbane, Australia.
► We assess particle number concentrations for popular bicycle commute routes.
► We calculate and compare inhaled particle count of routes from real-time data.
► Inhaled particle count is positively-associated with proximity to motorised traffic.

ARTICLE INFO

Article history:
Received 7 April 2012
Received in revised form
10 June 2012
Accepted 13 June 2012

Keywords:
Bicycle commuting
Motorised traffic
Ultrafine particles
Exposure concentration
Inhaled particle count

ABSTRACT

Frequent exposure to ultrafine particles (UFP) is associated with detrimental effects on cardiopulmonary function and health. UFP dose and therefore the associated health risk are a factor of exposure frequency, duration, and magnitude of (therefore also proximity to) a UFP emission source. Bicycle commuters using on-road routes during peak traffic times are sharing a microenvironment with high levels of motorised traffic, a major UFP emission source. Inhaled particle counts were measured on popular pre-identified bicycle commute route alterations of low (LOW) and high (HIGH) proximity to motorised traffic to the same inner-city destination at peak commute traffic times. During commute, real-time particle number concentration (PNC; mostly in the UFP range) and particle diameter (PD), heart rate, geographical location, and meteorological variables were measured. To determine inhaled particle counts, ventilation rate was calculated from heart-rate-ventilation associations, produced from periodic exercise testing. Total mean PNC of LOW, compared to HIGH, was reduced ($1.56 \times e^4 \pm 0.38 \times e^4$ versus $3.06 \times e^4 \pm 0.53 \times e^4$ ppcc; $p = 0.012$). Total estimated ventilation rate did not differ significantly between LOW and HIGH (43 ± 5 versus 46 ± 9 L min^{-1}; $p = 0.136$); however, due to total mean PNC, minute inhaled particle counts were 48% lower in LOW, compared to HIGH ($6.71 \times e^8 \pm 1.30 \times e^8$ versus $14.08 \times e^8 \pm 1.77 \times e^8$ particles total; $p = 0.003$). For bicycle commuting at peak morning commute times, inhaled particle counts and therefore cardiopulmonary health risk may be substantially reduced by decreasing proximity to motorised traffic, which should be considered by both bicycle commuters and urban planners.

1. Introduction

Atmospheric ultrafine particles (UFP) can be defined as those with a diameter of <0.1 μm, and these particles constitute the dominant diameter range within particle number concentration (PNC) values (Knibbs et al., 2011). Interest in the health implications of UFP has increased in the last two decades (Russell and Brunekreef, 2009; Wichmann and Peters, 2000), with general agreement that UFP possess greater toxicity potential than coarser particles due to relatively higher concentrations and surface area per mass (Donaldson et al., 2002; Li et al., 2003; Pietropaoli et al.,

Abbreviations: bpm, beats per minute; CBD, central business district; PM, particulate matter; PD, particle diameter; PNC, particle number concentration; ppcc, particles per cubic centimetre; UFP, ultrafine particle.

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http://dx.doi.org/10.1016/j.atmosenv.2012.06.041

2004; Wåhlin et al., 2001). Further, UFP has a greater ability to move through and beyond the pulmonary system (Elder et al., 2006; Nyström et al., 2009) so far as to elicit detrimental effects on the cardiovascular and nervous systems (Chan et al., 2004; McCreanor et al., 2007).

UFP exposure, and thus associated health risk, can vary with distance from a major emission source such as a motorised traffic corridor (Strak et al., 2010; Zuurbier et al., 2010). Proximity to motorised traffic emissions has been positively-correlated to pulmonary dysfunction and biomarkers of systemic inflammation (Jacobs et al., 2010). Accordingly, several studies have investigated the efficacy of reducing proximity to major roads to lower air pollution exposure concentrations when bicycle commuting (Giles et al., 2011). In addition to emission source proximity; commute duration will influence the potential UFP exposure of bicycle commuters (Hertel et al., 2008). Short episodes of particulate matter (PM) exposure may only elicit acute health detriments, however frequent episodes (e.g. daily commute-related exposure) could lead to increased susceptibility to chronic disease development in susceptible individuals (Dominici et al., 2006; Pope III, 2007). The effects of UFP on health, especially long-term, are not as well characterised as those of coarser PM.

Due to practical limitations associated with sensitivity, size and weight of monitoring equipment, limited knowledge is available on UFP exposure of bicycle commuter participants. Further, knowledge on the efficacy of lowering the proximity to motorised traffic to reduce UFP exposure is not comprehensive (Knibbs et al., 2011). Therefore, it was hypothesised that: 1) using a bicycle commute route of lower proximity to motorised traffic will facilitate a significant reduction in PNC, compared to a bicycle commute route of higher proximity to motorised traffic; 2) mean heart rate and associated pulmonary ventilation rate (as indices of physical effort) will not differ significantly between bicycle commute routes of low and high proximity to motorised traffic; 3) differences in inhaled particle counts between routes will predominantly be determined by PNC levels rather than physical effort (indicated by heart and ventilation rate).

2. Methods

2.1. Project design

Using a purpose-built bicycle-based system, popular pre-determined bicycle commute routes traversing Brisbane from the North, East, South and West suburbs to the CBD were repeatedly monitored, with variations of both high and low proximity to motorised traffic at morning peak traffic time, to: 1) quantify real-time and total mean PNC; 2) associate real-time and total mean heart rate to pre-determined heart-rate-ventilation associations; 3) compare particle exposure concentrations, heart-rate-ventilation associations and inhaled particle counts between high and low motorised traffic proximity variations of popular pre-determined bicycle commute routes.

2.1.1. Exposure profile monitoring

Popular commute routes and times for monitoring were identified and selected from previous research of regional bicycle commuters (Burke et al., 2010; and an initial study by the primary investigator). The participant (primary investigator) rode two pre-selected routes from four different origins (North, East, South, West suburbs) to the same destination (CBD), which were altered as either high (HIGH) or low (LOW) proximity to motorised traffic. The route conditions of HIGH or LOW were monitored in a counter-balanced order, on consecutive weekdays. Monitoring of each condition occurred on three different occasions to provide three return-trip data sets per condition and direction, for a total of twenty-four return trip data sets. The morning, rather than afternoon, commute peak hour was monitored because of commute departure time consistency, as well as meteorological consistency and reliability (Ayoko et al., 2005). The mean bicycle commute inbound departure time was indicated to be approximately 07:15, therefore the return trips (i.e. inbound and outbound) were performed between approximately 07:00 and 08:00 (an initial study by the primary investigator).

The monitoring period covered the months of December (2010) and January (2011), with a recess during the regional work holiday period (27th December, 2010 to 4th January, 2011) as related commuting traffic volume and thus emissions were expected to be atypical. Due to unfortunate circumstances (a major floodwater event in south-east Queensland in January, 2011) commute monitoring was also recessed from 11th to 18th January, 2011, as the Brisbane CBD was closed for business due to floodwater inundation, and some of the pre-determined commute routes were closed due to flooding and infrastructure damage.

This was a single-participant study with self-experimentation conducted in accordance with the principles of the Declaration of Helsinki. The participant was a 24 year old male of good health who is moderately aerobically-trained, with no history or indication of cardiopulmonary disease, normal lung function ($FEV_1/FVC \geq 80\%$), normal Body Mass Index (23.5 kg m^{-2}), a resting heart rate of <80 bpm, and a maximal aerobic capacity of 52 mL kg^{-1} min^{-1}.

2.1.2. Geography of monitored region

Brisbane is Australia's third largest city, and the capital of the state of Queensland, located on the state's southern coast. It is separated by a large river, named after the city, and is consequently located in a low-lying floodplain, with several large hills of up to 300 m in height and bordered to the west by a coastal range. At a latitude of 27° South, the regional climate is sub-tropical, being cool and dry in Winter between June to August, and humid and wet in Summer between December to February. The city has a population of approximately two million people, which has continued to grow by approximately two percent annually for the last two decades. Brisbane's motorised traffic volume is currently moderate compared to the two larger Australian cities, Sydney and Melbourne; however, along with population growth, motorised traffic numbers are increasing, particularly due to residential development in outer suburbs and satellite towns. Industrial air pollution sources include a major airport, seaport, and oil refineries approximately 15 km north-east from the central business district (CBD), a coal power station approximately 30 km south-west of the CBD, and various factories in the outer suburbs.

2.2. Air quality monitoring

2.2.1. In-commute particle exposure concentration and diameter

Real-time PNC and particle diameter (PD) were recorded and logged in-commute with 16-s means using a portable, compact (165 × 95 mm) and lightweight (750 g) UFP monitoring unit (Aerasense NanoTracer; Philips, The Netherlands). The NanoTracer device is capable of measuring PNC [0–e^6 particles per cubic centimetre (ppcc)] and PD [10–300 nm (nanometres)] via particle-charging rather than particle-condensation (Marra et al., 2009). Calibration of the NanoTracer was performed in an exposure chamber of low PNC with 48 h of continuous recording and subsequent referencing to a water-based condensation particle counter (WCPC 3781; TSI Inc., USA) at the end of the monitoring period. Accordingly, an appropriate correction factor was applied to raw data prior to analyses (see Section 2.7 Statistical Data Analysis,