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Investigations into factors affecting personal exposure to particles in urban microenvironments using low-cost sensors

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ABSTRACT

Epidemiological studies have linked outdoor $PM_{2.5}$ concentrations to a range of health effects, although people spend most of the time indoors. To better understand how individuals' exposure vary as they move between different indoor and outdoor microenvironments, our study investigated personal $PM_{2.5}$ exposure and exposure intensity of 14 adult volunteers over one week (five weekdays and one weekend), using low-cost personal monitors, recording $PM_{2.5}$ concentrations in 5 min intervals. Further, the study evaluated community perception of air pollution exposure during the recruitment and engagement with the volunteers. We found that people with tertiary education across all ages had greater interest in participating, with younger people being interested regardless of the level of education. The derived exposures and exposure intensities differed between weekdays and the weekend due to larger variations in individuals' daily routines. In general, time spent at home and engaged in indoor activities was associated with the highest personal $PM_{2.5}$ exposure and exposure intensity on both, week and weekend days, implying the significance of both duration of the exposure and the indoor $PM_{2.5}$ concentrations. The results showed no relationship between personal exposures and indoor characteristics of home (ventilation, building age and cooktop), which are expected to be due to the study's small sample size. The observed $PM_{2.5} > 10\,\mu g\,m^{-3}$ were significantly higher for distances < 50 m to the roads for both major and minor roads, and were observed in areas with < 16% open space, which were also close to a major road.

1. Introduction

The World Health Organisation (WHO) classified exposure to ambient particulate matter and air pollution in general, as the leading environmental cause of cancer deaths in humans (International Agency for Research on Cancer (IARC), 2013). A recent global burden of disease (GBD) study assessing 79 risk factors reported that behavioural risk as a result of smoking as well as environmental risks due to exposure to household and ambient air pollution in terms of particulate matter smaller than 2.5 µm ($PM_{2.5}$) were in the top 8 leading risks to the GBD in 2015 for both sexes (Forouzanfar et al., 2016). Although the public perception might be that Australia enjoys a good air quality in comparison to other parts of the world, air pollution is one of the top environmental risk factors in Australia (Australian Institute of Health and Welfare, 2012). Assessing personal exposure to air pollution gives a more realistic assessment of the individuals' spatiotemporal exposure in comparison with basing the assessment on fixed-site ambient monitoring; especially in relation to indoor and commuting exposures. There has been a growing interest in quantifying exposures using personal monitors (Buonanno et al., 2011; Haynes et al., 2012; Mazaheri et al., 2014; Bekö et al., 2015; Nieuwenhuijsen et al., 2015; Steinle et al., 2015; Wangchuk et al., 2015) as well as using estimates of

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personal exposures by investigating association between air pollution with different health measures and for different population groups (Janssen et al., 2005; Jacquemin et al., 2007; Dadvand et al., 2012; Schembari et al., 2013).

In urban areas of developed countries, indoor concentrations of particles at home and office environments are mainly driven by the infiltration of outdoor particles through building structures, natural ventilation, indoor activities (e.g. cooking, cleaning) and presence of particle sources (e.g. heaters, printers, smoking) (Morawska et al., 2013; Morawska et al., 2017). These studies have pointed to the important contribution of different indoor activities and environmental factors to $PM_{2.5}$ concentrations and air quality in general, and demonstrated that ambient particles are mainly influenced by urban sources including vehicular traffic, airport and port operations (Morawska et al., 1998; Mueller et al., 2011; Masiol and Harrison, 2014; Rahman et al., 2017). However, understanding the complex interactions between the factors driving personal exposure to air pollution requires further research using real-time personal monitors, coupled with detailed information of the individuals' activities and the sources of air pollution in their proximity. The complexity is higher for people living in dynamic urban environments (Lewis and Edwards, 2016; Morawska et al., 2018; WMO, 2018).

The new era of smartphone technology coupled with public access to data has revolutionised data collection methods in relation to public health. The recently emerged "mHealth" or "mobile health" services have been utilised during the past few years following the fast-paced growth and advances in mobile phone technologies as well as their popularity within all age groups. mHealth services use text messages and applications for crowd-sourcing air quality data (Thompson, 2016) as well as providing healthcare programs to the citizens, such as for quit smoking (Fiordelli et al., 2013; Hall et al., 2015). The fast-growing field of sensing technology has made a range of low-cost air quality sensors available in the market. These sensors are easy to use and most of them provide quantitative information of pollutant concentrations or index values of different air quality parameters.

The aim of this research was to estimate and apportion personal $PM_{2.5}$ exposures (defined as average $PM_{2.5}$ concentration times corresponding duration of activity or time spent in a microenvironment) and exposure intensities (defined as the portion of the 24-h $PM_{2.5}$ exposure received in a microenvironment divided by the portion of the day spent in that microenvironment). This paper used personal $PM_{2.5}$ concentrations measured by low-cost personal monitors during a weekday and weekend for healthy, full-time office workers. Analysis includes assessing different aspects of users' involvement and life-style factors influencing personal exposure to $PM_{2.5}$. In addition, urban characteristics such as the impact of nearby vehicular traffic and surrounding land-use on the received exposures during commutes and the times spent indoors and outdoors were investigated and discussed. The outcomes are not limited to the study area and have implications on assessing personal exposures at indoor and outdoor microenvironments with respect to everyday life activities using the increasing availability of low-cost air quality monitors.

2. Materials and methods

2.1. Study design

Data collection was conducted from May to October 2016, involving participation of 14 adult volunteers. No monetary reward was offered for the participation to attract people that are highly motivated. Invited to participate were independent/healthy adult office-workers, aged 21 and over (male or female), who did not require any special care, worked full-time and whose residences or common places of activity were spatially diverse and within the Brisbane Metropolitan Area (BMA) in Queensland, Australia. Recruitment was through advertisements at the Queensland University of Technology (QUT). QUT has over 12,000 staff members and its campuses are located within the BMA (statistics for the 2014-2015 financial year; https://www.qut.edu.au/about/our-university/qut-at-a-glance). The research was also promoted to non-QUT community through word of mouth and advertising on social media. This study was approved by the QUT Human Research Ethics Committee (approval number 1500001251).

2.2. Instrumentation

This work used the Aircasting platform incorporating Airbeam personal air quality and environmental monitor to estimate and apportion personal $PM_{2.5}$ exposures and exposure intensities, which is one of the emerging low-cost platforms (249 USD; http://aircasting.org). The Airbeam is a low-cost personal monitor (dimensions: 105 × 95 × 43.5 mm, weight: 198.5 g), which uses Shinyei PPD60PV-T2 sensor to estimate $PM_{2.5}$ concentrations, and MaxDetect RH03 sensor for temperature and relative humidity. When fully charged, the Airbeam battery lasts up to 7 h. The Airbeam is coupled with the Aircasting App that is compatible with Android-based smartphones (version 4.4.2 and above) via Bluetooth connection. The Aircasting App is capable of recording, displaying and sharing time-series of personal $PM_{2.5}$ concentrations, temperature and relative humidity together with the geolocations using the GIS data captured by the smartphone. The real-time instantaneous data can be viewed on the Smartphone using the Aircasting App, together with the historical measured data as a heatmap. Four Airbeams were used in this study and they were programmed to record the averaged data every 5 min. In this paper, we used the measured estimates of $PM_{2.5}$ concentrations and geolocation time-series.

The results of preliminary measurements to evaluate the Airbeam performance in measuring $PM_{2.5}$ concentrations at ambient levels of Brisbane that are generally lower than 10 μg m^{-3} (Queensland Department of Environment and Heritage Protection: https://www.ehp.qld.gov.au/air/data/search.php) showed that they were able to pick up the microscale variation in the $PM_{2.5}$ concentrations. Since no concurrent ambient $PM_{2.5}$ data were available at participants' locations of residence and work, the Airbeam was considered suitable for this study and no correction factor was applied to the measured concentrations. It should be noted that the $PM_{2.5}$ readings from the Airbeams were not treated as absolute concentrations, rather they were used as estimates to study fine-scale variations in personal exposures during day-to-day activities. Hence, the presented concentrations should be used as estimates only and the analysis relies on comparing the relative influence of life-style factors on the estimates of $PM_{2.5}$ exposures and exposure intensities between participants rather than their absolute values.

2.3. Personal exposure and exposure intensity

Main analysis of this paper is based on estimating and apportioning personal $PM_{2.5}$ exposures (defined as average $PM_{2.5}$ concentration times corresponding duration of activity or time spent in a microenvironment) and exposure intensities (defined as the portion of the 24-hour $PM_{2.5}$ exposure received in a microenvironment divided by the portion of the day spent in that microenvironment) (Buonanno et al., 2011; Buonanno et al., 2012; Mazaheri et al., 2014; Wangchuk et al., 2015).

Data collection was carried out through volunteer participation and involved (a) completing a multiple-choice study questionnaire that took approximately 10 min and contained information on the participants' age and gender, socio-economic status (highest qualification) and characteristics of the indoor and outdoor environments during weekdays and weekend, such as age for their residence, ventilation conditions at home and work, type of cooktop at home and commuting preferences; (b) using the Aircasting App coupled with their own Android-based smartphone and carrying a Airbeam personal monitor using a dedicated clip or keeping it within their close proximity,