Atmospheric Environment 180 (2018) 103–109

Contents lists available at ScienceDirect

Atmospheric Environment

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

A panel study of airborne particulate matter concentration and impaired cardiopulmonary function in young adults by two different exposure measurement

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ARTICLE INFO

Keywords:
$PM_{2.5}$
Personal exposure
Cardiopulmonary function
China

ABSTRACT

This study sought to clarify the correlation of individual exposure measurements and $PM_{2.5}$ measurements collected at regulatory monitoring sites in short-term panel study settings. To achieve this goal, 30 young, healthy adult participants were assigned to three groups with 4 samplers in each group to collect individual exposures during four weekends in March 2016. Participants also completed cardiopulmonary function tests during the same periods. For comparison, ambient air pollution data were obtained from the Air Pollution Surveillance Network in Guangzhou, China. The 8-h ambient pollutant averages and group sampler concentrations were used as separate indicators of air pollution exposure. Results showed that the 8-h mean concentration of personal $PM_{2.5}$ exposure was 65.09 ± 22.18 μg/m^3, which was 24.34 μg/m^3 statistically higher than the ambient concentrations over the same period ($p < 0.05$). However, these concentrations were strongly correlated (Spearman's $r = 0.937$, $p < 0.01$). Separate mixed-effect models were fit for ambient and personal exposures to estimate their associations with cardiopulmonary outcomes. Higher $PM_{2.5}$ and PM_{10} exposures were related to lower lung function of maximal mid-expiratory flow (MMEF). A 10 μg/m^3 higher PM was associated with 0.11 L/S to 0.52 L/S lower MMEF. No effects on cardiovascular function were found. In conclusion, personal $PM_{2.5}$ exposure might be higher than ambient concentrations. Young, healthy adults in urban areas may experience reduced lung function (lower MMEF), even after just 8 h of exposure to $PM_{2.5}$ and PM_{10}.The comparatives of the effects of ambient pollutant and individual concentrations on human health will help to understand the validity of utilizing ambient monitoring as a surrogate for individual exposure assessment.

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https://doi.org/10.1016/j.atmosenv.2018.03.001
Received 26 June 2017; Received in revised form 27 February 2018; Accepted 1 March 2018
Available online 02 March 2018
1352-2310/

1. Introduction

Particulate matter with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$), is a major pollutant which causes haze in China and many other countries (Kuehn, 2014; Ministry of Environmental Protection of the People's Republic of China, 2015; World Health Organization, 2009). Since $PM_{2.5}$ has a large surface area, it can absorb large amounts of harmful substances (such as heavy metals, acidic oxides, microorganisms etc.), and because of the small diameter, it can enter the deeper parts of the respiratory tract and penetrate into the bronchioles and alveoli, thus causing impaired cardiopulmonary function (Ierodiakonou et al., 2016; Nina et al., 2010; Zhang et al., 2002). Several studies have documented that $PM_{2.5}$ significantly disrupts cardiopulmonary health (Chang et al., 2015; Gauderman et al., 2015; Liu et al., 2016; Watanabe et al., 2016; Wong et al., 2016; Wu et al., 2013a, 2013b; Zhao et al., 2015), including short-term health effects on lung function and increased blood pressure, especially in susceptible people (e.g., young children and those with chronic obstructive pulmonary disease or asthma).

However the strength of the relationship between $PM_{2.5}$ and cardiopulmonary function has not been sufficiently emphasized (Jerrett et al., 2005; Lagorio et al., 2006; Sarnat et al., 2012; Setton et al., 2011; Strak et al., 2010; Watanabe et al., 2016). On one hand, various components of $PM_{2.5}$ in different sites can influence the effects (Gauderman et al., 2000; McCreanor et al., 2007). On the other hand, the precise assessment of $PM_{2.5}$ exposure plays an important role in understanding the strength of relationships between $PM_{2.5}$ and various health effects.

Individual exposure measurement, where pollution is measured using personal wearable devices (as relatively to utilizing aggregate environmental measurements from monitoring stations), can better quantify observed differences and better reflect exposure among smaller groups of people at ground level. Some consider this to be the most accurate method of pollutant exposure assessment (Sheppard et al., 2012; USEPA, 1992). However, due to the burden of individual exposure assessment, epidemiologic studies have primarily relied upon the more readily available data from environmental monitoring stations to estimate individual's $PM_{2.5}$ exposure (Brook et al., 2011; Trenga et al., 2006) or often through land use regression and spatio-temporal modeling approaches (Kloog, 2016; Lee et al., 2011; Ma et al., 2016; Van Donkelaar et al., 2015). These model approaches can now render predictions of $PM_{2.5}$ concentrations at fine scales such a 1 × 1 km. Several exposure studies have indicated that personal exposure is associated with measurements from monitoring stations or those predicted by statistical models (Avery et al., 2010; Boudet et al., 2001; Ducret-Stich et al., 2012; Wu et al., 2016). In addition, a growing number of panel studies on short-term air pollution exposures have assessed personal exposure based on ambient air concentrations measured at fixed stations within 3 km or even less than 1 km of their movement, such as community concentrations (Zauli Sajani et al., 2004; Zhao et al., 2015). The association between personal exposure to $PM_{2.5}$ and ambient $PM_{2.5}$ concentration has only been characterized for limited populations in a few locations in these studies (Avery et al., 2010; Boudet et al., 2001; Delfino et al., 2008; Mehta et al., 2014; Meng et al., 2012). The validity of utilizing ambient monitoring as a surrogate for individual exposure assessment still requires further scrutiny.

Our objective was to compare the $PM_{2.5}$ concentrations from individual monitoring of young, healthy adults with those estimated by monitoring stations at the 1.5 km scale utilizing the panel study framework. We then compared the estimated impact of differential $PM_{2.5}$ exposure assessment on cardiopulmonary function.

2. Materials and methods

2.1. Study participants and sampling method

Participants for this study were recruited from Sun Yat-sen University in Guangzhou, China. Eligibility criteria for study inclusion included ages 16–39, and self-report of general good health during the past week. General good health was defined as not having had a cough, wheeze, shortness of breath, and/or chest tightness symptoms during the previous week. Participants were excluded if they self-reported ≥1 of the aforementioned respiratory symptoms within the previous week or if they self-reported drinking alcohol or smoking. This resulted in a total of 30 participants who met the eligibility criteria for our study. Prior to enrollment, we obtained written informed consent from all eligible participants. This study was approved by the Sun Yat-sen University Institutional Human Ethics Committee (Ethics Approval Number: L2016016).

2.2. Individual exposure measurement

Participants were randomly assigned to one of three exposure groups, with 10 participants assigned to each group. The participants in each exposure group were required to stay within a 1.5 km radius of three distinct monitoring stations in Guangzhou city. The participants were instructed to perform their regular activities and to avoid unusual physical activity or strenuous exercise as a group for 8 h, three consecutive days (Saturday, Sunday, Monday), within each of the 4 consecutive weekends of March 2016. Each group carried four devices of two types of filters during the 8-h periods (9:00am to 5:00pm): 2 devices to measure $PM_{2.5}$ concentrations with Teflon filter and another 2 devices to measure $PM_{2.5}$ with quartz filter for further chemical analysis. In this study, only the $PM_{2.5}$ concentrations with Teflon filter were analyzed. Groups reported activities such as playing cards, reading books, browsing the web via their mobile devices, and taking short walks together during the 8-h sampling periods. In addition to these personal measurements, environmental $PM_{2.5}$, particulate matter with an aerodynamic diameter of 10 μm or less (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3) concentrations, temperature, and humidity for the same observation days were recorded as reported by the Guangzhou meteorological service (http://www.tqyb.com.cn/gz/weatherAlarm/) monitoring stations. A detailed description of air pollution exposure measurements were shown in eAppendix 1. For the purpose of this analysis, we only examined associations between personal $PM_{2.5}$ exposures and ambient particulate matter concentrations simultaneously measured by the fixed air quality monitoring networks.

The BUCK-Libra Plus (A.P. BUCK, USA) individual sampler was used for personal monitoring of $PM_{2.5}$. Inside the sampler was a 37 mm diameter Teflon or quartz filter where $PM_{2.5}$ is captured. The pump of the sampler was carried in the participant's backpack/handbag whereas the filtered sampler was affixed near the participant's shirt collar in order to monitor the ambient environment near the participant's airway. The sampling filters were collected at the end of each sampling day and at the end of the sampling, they were weighed by the same automatic weighing system (AWS-1, COMDE DERENDA, Germany, approved by European Standard) which sensitivity is 0.001 mg as it was done before the sampling with controlled temperature (20 ± 1 °C) and humidity (50% ± 5%) (Bai et al., 2017; Wang et al., 2016).

2.3. Cardiopulmonary function measurement

The cardiopulmonary function tests were conducted at the close of the 8-h sampling periods. Before the test, the participants were instructed to stay relaxed and seated for at least five minutes of quiet rest. During each test, two portable electronic spirometers (Spirolab, MIR, Italy) were utilized to measure pulmonary functions including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), peak expiratory flow (PEF), and maximal mid-expiratory flow (MMEF). These lung function data were collected following the standards of the American Thoracic Society (ATS) and European Respiratory Society (ERS) (Alexandraki et al., 2010; Ma et al., 2013, 2015). Each