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Short-term effects of particulate matter in metro cabin on heart rate variability in young healthy adults: Impacts of particle size and source

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ABSTRACT

Background: Metro system has become popular in urban areas. However, short-term effects of size-fractionated particulate matter (PM) on cardiac autonomic function in metro system remain unexplored.

Objectives: To explore the contribution of ambient PM to in-cabin PM and investigate the short-term effects of exposure to size-fractionated PM and black carbon (BC) in metro system on cardiac autonomic function in young healthy adults.

Methods: Thirty nine young healthy adults were asked to travel in metro system during 9:00–13:00 on a weekends between March and May 2017. We performed continuous ambulatory electrocardiogram monitoring for each of them, and measured real-time size-fractionated PM, BC, nitrogen dioxide, nitric oxide, carbon dioxide, ozone, noise, temperature and relative humidity in metro cabin. We also collected the data of ambient $PM_{2.5}$ (aerodynamic diameter < 2.5 µm) concentrations in Beijing. Linear regression model was used to estimate the infiltration factor of ambient $PM_{2.5}$ to assess the relationship between metro cabin PM and ambient PM. Mixed-effects model was used to estimate the associations between changes in HRV parameters and $PM_{0.5}$ (aerodynamic diameter < 0.5 µm), $PM_{0.5-2.5}$ (aerodynamic diameter between 0.5 µm and 2.5 µm), $PM_{2.5-10}$ (aerodynamic diameter between 2.5 µm and 10 µm), and BC, respectively.

Results: We found that size-fractionated PM in metro systems were significantly associated with HRV parameters. Per IQR (interquartile range) increase in $PM_{0.5}$ ($1.6*10^7/m^3$) in 1-h moving average concentration was associated with a 13.96% (95% CI: − 18.99%, − 8.61%) decrease in SDNN (standard deviation of normal-to-normal intervals). Similar inverse associations were found between size-fractionated PM exposure and LF (low frequency power), HF (high frequency power), respectively, and smaller particles had greater effects on HRV parameters at shorter lag time. Sex of participants modified the adverse associations between size-fractionated PM and HRV. An IQR of 1-h $PM_{0.5}$ increasing was associated with a decrease of 6.05% (95% CI: − 22.87%, − 14.44%) in males and a 34.87% (95% CI: − 49.59%, − 15.85%) in females in LF (P for interaction = 0.026). The infiltration factor of ambient $PM_{2.5}$ was 0.39 (95% CI: 0.33, 0.45). It is estimated that $PM_{2.5}$ originated from ambient air may account for 20.2% of the PM measured in metro cabin. Per IQR increase in BC (5.5 µg/m^3) in 5-min, 1-h, and 2-h moving averages, a primary tracer for ambient PM from combustion source, was associated with decreases of 0.84% (95% CI: − 1.20%, − 0.47%), 2.22% (95% CI: − 3.20%, − 1.22%), and 4.44% (95% CI: − 6.28%, − 2.56%) in SDNN, respectively.

Conclusions: Short-term exposure to PM may disturb metro commuter's cardiac autonomic function, and the potential effects depend on the size of PM and the sex of commuters. Ambient PM from combustion source may have adverse effects on the cardiac autonomic function of passengers in cabin.

1. Introduction

With the rapid development of urbanization, metro system has become the most popular option for commuters in many urban areas, and the number of metro trains and commuters has increased significantly over recent years. The metro microenvironment is composed of confined spaces where particulate matter (PM) may accumulate to a higher level than in ambient air, especially when encountering facilities and trains have inefficient air conditioning and ventilation system (Moreno et al., 2014; Nieuwenhuijsen et al., 2007; Martins et al., 2016; Kim

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et al., 2017).

In-cabin PM concentration is worthy of investigation as metro commuters typically spend majority of their time staying inside cabins when commuting by metro system (Kam et al., 2011). The PM inside cabins mainly originate from two sources, non-ambient sources and ambient source (Li et al., 2017a). Non-ambient PM refers to those originated from sources in the metro microenvironments, such as the wheel-rail mechanical abrasion emissions, brake pads, and resuspension of dust particles (Kang et al., 2008; Querol et al., 2012; Kam et al., 2011). In addition, ambient PM levels and infiltration factors could also affect PM concentration inside metro cabins (Moreno et al., 2017; Li et al., 2017b). A study in Hong Kong showed that the infiltration factors of $PM_{2.5}$ in metro cabin varied between 0.2 and 0.3 (Li et al., 2017a).

Black carbon (BC), a constituent of fine particles, has no source other than combustion and is relatively stable once being released (Invernizzi et al., 2011). BC enters the metro system through the air conditioning system in metro which draws air from above-ground air vents. Despite the existence of the filtration facilities, blocking BC away is hard because of its fairly small size (Li et al., 2015). In addition, there is no source of combustion in the metro system. Therefore, BC in metro could be considered as a primary tracer for ambient PM from combustion source.

Altered cardiac autonomic function, as reflected by changes in heart rate variability (HRV), is considered as a possible pathophysiologic pathway of PM influences on cardiovascular system (Pope et al., 2003; Rhoden et al., 2005; Munzel et al., 2016). Previous studies have found that exposure to traffic-related PM could influence the cardiac autonomic regulation of young healthy adults (Wu et al., 2011; Weichenthal et al., 2014; Colehunter et al., 2016). A recent epidemiological study suggests that the association between indoor PM exposure and the changes in HRV parameters attenuated with increasing particle size among patients with chronic obstructive pulmonary disease (Pan et al., 2018). However, it remains unclear whether exposure to size-fractioned PM could have significant impact on HRV in healthy subjects in the microenvironment of metro cabin, and whether ambient PM exposure has adverse effects on HRV in metro commuters.

To explore the cardiac autonomic effects of exposure to size-fractioned PM, we conducted a repeated-measure study among young healthy adults in metro in Beijing. The specific objectives of this study were to: a) quantitatively evaluate the percent changes of HRV corresponding to the increase of size-fractioned PM concentration in metro by controlling for potential confounding variables; b) estimate the contribution of ambient PM to the concentration of in-cabin PM and related health effects in metro commuters.

2. Materials and methods

2.1. Participants and protocol

We conducted a repeated-measure study from March to May 2017 in metro with a ring route, which is located between the 3rd Ring Road and the 4th Ring Road of Beijing urban area. Forty college students were recruited. A face-to-face interview questionnaire was used to collect their personal information, including name, sex, age, body mass index (BMI), smoking status and medical history. To reduce the heterogeneity of participants, we used the following inclusion criteria to choose participants: nonsmoking; no history of physician-diagnosed cardiovascular, pulmonary, neurologic, or endocrine diseases. Research protocol and consent forms were approved by the Institutional Review Board of Peking University Health Science Center (RIB number 00001052-16066). All participants were well informed and signed consent forms.

Each participant was required to finish a travel for approximately 4 h between 9:00–13:00 on a weekend between March and May 2017. During the travel, participants were required to stay in the middle of a metro cabin, and continuous personal environmental monitoring and ambulatory ECG monitoring were performed for each of them over the travel periods.

2.2. Environmental exposures

Air pollutants, noise, temperature (Temp) and relative humidity (RH) were measured continuously when participants stayed inside cabins. The concentrations of size-fractioned PM, including $PM_{0.5}$ (aerodynamic diameters < 0.5 μm), $PM_{2.5}$ (aerodynamic diameters < 2.5 μm), and PM_{10} (aerodynamic diameters < 10 μm), were measured by a real-time particulate counter (Model Handheld PC3016; GrayWolf Inc., USA). Meanwhile nitrogen dioxide (NO_2), nitric oxide (NO), ozone (O_3), and carbon dioxide (CO_2) were measured by an indoor air quality meter (Model TG-503; GrayWolf Inc., USA). These two instruments were used in previous studies to monitor indoor air quality (Pan et al., 2018; Birger et al., 2011; Su et al., 2011). Black carbon concentration was measured by a portable micro-Aethalometer (microAeth Model AE51; Magee Scientific, Berkeley, CA, USA). Intensity of noise was measured by a portable noise meter recording continuous equivalent sound levels (Leq) in A-weighted decibels (dBA) (Model ASV5910; Hangzhouaihua Inc., Hangzhou, CHINA). In addition, real-time data of Temp and RH were recorded by a Temp/RH meter (Model WSZY-1B; Tianjianhuayi Inc. Beijing CHINA). All the monitoring instruments were carried by field investigators, who stayed less than 1 m away from the participants over the travel periods. Specifically, the sampling height was about 1 m above the cabin floor to match participants' breathing zone at a sitting position. The real-time concentrations of size-fractioned PM and BC, gaseous pollutants, as well as levels of noise, Temp and RH were all logged at 5-min intervals.

We collected hourly $PM_{2.5}$ concentration data from fixed monitoring stations of Beijing Municipal Environmental Monitoring Center whose data were available for online download (http://www.bjmemc.com.cn/). We chose six stations' data because these stations just locate around the ring route.

2.3. Ambulatory ECG monitoring

Each participant wore a 12-channel ambulatory ECG (Holter) monitor (model MGY-H12; DM software Inc., USA) during the trip. Investigators helped participants wear the Holter recorders in our laboratory before starting off. The ECG digital recordings were processed by technicians using the software for the Holter recorder (Holter System, Version 12.net; DM Software Inc., USA). Each 5-min segment of NN intervals was extracted for parameters calculation. All noise and abnormities were excluded based on standard criteria (Camm et al., 1996). Finally, one time-domain parameter, standard deviation of normal-to-normal intervals (SDNN), and three frequency-domain parameters, high frequency power (HF, 0.15–0.40 Hz), low frequency power (LF, 0.04–0.15 Hz) and LF/HF ratio, were calculated.

To reduce any potential influence on HRV, food and drink containing alcohol or caffeine, and high-intensity physical activities were forbidden from 24 h before the travel began until the end of the travel. During the trip in metro, participants kept sitting and were prohibited from listening to music or watching videos. Some pre-prepared candies were distributed to participants at about 11:00 to avoid hypoglycemia which might disturb the HRV.

2.4. Data processing and statistical analysis

Microenvironment exposures and HRV data were checked for completeness and abnormal values on site immediately, and missing data would be fulfilled if necessary. We calculated the mass concentration of $PM_{2.5-10}$ by subtracting $PM_{2.5}$ from PM_{10}, and the same method was applied to calculate the mass concentration of $PM_{0.5-2.5}$. We used mass concentrations for $PM_{0.5-2.5}$ and $PM_{2.5-10}$. However, due to the small mass content of $PM_{0.5}$, we chose to use its number