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Cardiorespiratory responses of air filtration: A randomized crossover intervention trial in seniors living in Beijing
Beijing Indoor Air Purifier StudY, BIAPSY

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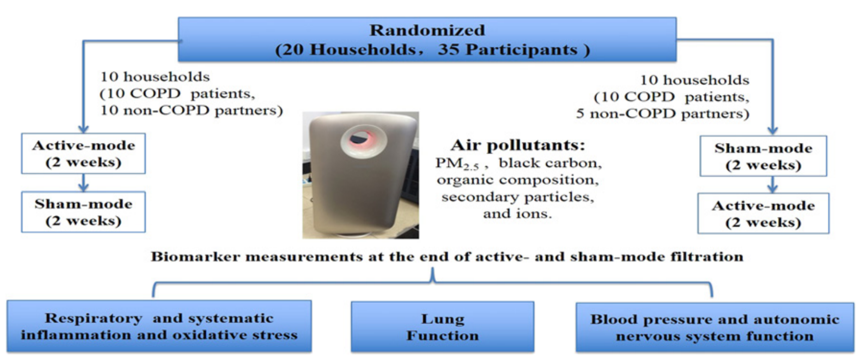
HIGHLIGHTS

- Air filtration can significantly reduce indoor air pollution levels.
- Short-term indoor air intervention can be of limited health benefit in areas with extreme high outdoor pollution.
- Health benefit of longer term intervention is worth investigation for vulnerable participants.

GRAPHICAL ABSTRACT



Abbreviations: $PM_{2.5}$, Particulate matter with an aerodynamic diameter <2.5 μm; COPD, chronic obstructive pulmonary disease; SNS, sympathetic nervous system; HEPA, high efficiency particulate air; BP, blood pressure; EBC, exhaled breath condensate; CRP, C-reactive protein; IL, interleukin; FEV1, forced expiratory volume in 1 second; BIAPSY, Beijing Indoor Air Purifier StudY; BC, black carbon; PUTH, Peking University Third Hospital; FVC, forced vital capacity; HRV, heart rate variability; CADR, clean air delivery rate; SBP, systolic BP; MAP, the mean arterial BP; IRB, The Institutional Review Board; PUHSC, Peking University Health Science Center; TEOM, tapered element oscillating balance method; ETC, elapsed time counters; WSTC, water-soluble total carbon; WSOC, water-soluble organic carbon; NO_3^-, nitrate; SO_4^{2-}, sulfate; Zn^{2+}, zinc ions; Pb^{2+}, lead ions; K^+, potassium ions; ESCAPE, the European Study of Cohorts for Air Pollution Effects; BMI, body mass index; CAT, COPD Assessment Test; ELISA, enzyme linked immunosorbent assay; CBA, Cytometric Bead Array; DBP, diastolic BP; SDNN, standard deviation of NN intervals; RMSSD, the square root of the mean of the squared differences between adjacent normal-to-normal intervals; LF, low frequency; HF, high frequency; TP, total power; SD, standard deviation; LME, linear mixed-effect; AIC, Akaike's information Criterion; CI, confidence interval; IQR, interquartile range.

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ABSTRACT

In this *B*eijing *I*ndoor *A*ir *P*urifier *S*tud*Y* (BIAPSY), we conducted a randomized crossover intervention trial in a panel of 35 non-smoking senior participants with free-living, with and without chronic obstructive pulmonary disease (COPD). Portable air filtration units were randomly allocated to active-(filter in) for 2 weeks and sham-mode (filter out) for 2 weeks in the households. We examined the differences in indoor air pollutant concentrations in 20 study homes and a suite of cardio-respiratory biomarker levels in study participants between filtration modes, with and without adjustment for potential confounders. Following active filtration, we observed significant reductions from 60 ± 45 to 24 ± 15 μg/m^3 in ten-day averages of indoor $PM_{2.5}$ and reductions from 3.87 ± 1.65 to 1.81 ± 1.19 $m^{-1}.10^{-5}$ in ten-day averages of indoor BC, compared to sham-mode filtration. The major components of indoor $PM_{2.5}$, including water soluble organics, NO_3^-, SO_4^{2-}, Zn^{2+}, Pb^{2+} and K^+, were also reduced significantly by 42% to 63%. However, following active filtration, we only observed significant reductions on systemic inflammation measured as of IL-8 at 58.59% (95% CI: −76.31, −27.64) in the total group of participants and 70.04% (95% CI: −83.05, −47.05) in the subset of COPD patients, with adjustments. We were not able to detect improvements on lung function, blood pressure, and heart rate variability, following short-term intervention of two-week active air filtration. In conclusion, our results showed that indoor air filtration produced clear improvement on indoor air quality, but no demonstrable changes in the cardio-respiratory outcomes of study interest observed in the seniors living with real-world air pollution exposures.

1. Introduction

Particulate matter with an aerodynamic diameter <2.5 μm ($PM_{2.5}$) air pollution is the ninth leading risk factor for the global disease burden and can cause myocardial infarction, stroke, heart failure, asthma, chronic obstructive pulmonary disease (COPD) and lung cancer (Brook et al., 2010; Lim et al., 2012; Wright and Brunst, 2013). Several underlying mechanisms have been elucidated that air pollution-induced cardio-respiratory abnormalities, including sympathetic nervous system (SNS) activation, vascular dysfunction, and respiratory and systemic inflammation, are likely the critically important pathways in the genesis of chronic cardiovascular and respiratory diseases (Brook et al., 2010; Laumbach et al., 2015; Newby et al., 2015). Given that epidemiological evidence support a near linear concentration-response relationship without a lower threshold between $PM_{2.5}$ concentrations and adverse health effects, reductions in $PM_{2.5}$ can translate into clear health benefits (Huang et al., 2012a; Morishita et al., 2015; Rich et al., 2012; Zhang et al., 2013).

Studies reported that high efficiency particulate air (HEPA) filters can trap >99% of ambient particles with diameter >0.3 μm and reduce indoor PM mass and number concentrations by >50% (Batterman et al., 2012; Ward et al., 2017; Wheeler et al., 2014), with some evidence that there are also associated improvements in cardiovascular and respiratory parameters (Fisk, 2013; Morishita et al., 2015). Collectively, these studies have reported that the use of air purifiers may be associated with reductions in blood pressure (BP), respiratory inflammation and oxidative stress (acidity pH, 8-isoprostane, nitrite, and the sum of nitrite and nitrate in exhaled breath condensate, EBC), systemic inflammation (C-reactive protein, CRP, and interleukin-6, IL-6), and improvement in lung function (forced expiratory volume in 1 s, FEV1) (Brauner et al., 2008; Chen et al., 2015; Kajbafzadeh et al., 2015; Karottki et al., 2013; Karottki et al., 2015; Lin et al., 2011; Padro-Martinez et al., 2015; Weichenthal et al., 2013; Xu et al., 2010). However, few HEPA intervention studies were conducted in free-living participants residing in their own homes to evaluate the potential health benefits from real-world conditions (Allen et al., 2011).

China currently undergoes enormous industrialization and urbanization leading to air pollution and health problems, and it is a great challenge for the government to reduce air pollution and its contribution to life loss dramatically in the near future (Huang et al., 2014; Li and Zhang, 2014). The average annual concentration of $PM_{2.5}$ in 338 Chines cities was 50 μg/m^3 (ranging from 11 to 125 μg/m^3) in 2015, which was approximately 43% higher than the national annual air quality standard of 35 μg/m^3 (China Environment Bulletin, 2015). Further, indoor air pollution in Chinese households are mainly from the infiltration of outdoor air and the emissions from indoor sources, such as cooking oil fumes, smoking, and human activities (Chao and Cheng, 2002; He et al., 2004). Given that indoor air pollution levels are highly correlated with outdoor levels (Han et al., 2015), indoor air filtration of air pollutants from outdoor origins may have benefits for public health in China, especially for susceptible individuals with chronic diseases and children in real-world conditions (Fisk, 2013; Laumbach et al., 2015).

In this *B*eijing *I*ndoor *A*ir *P*urifier *S*tud*Y* (BIAPSY), we aimed to evaluate if the use of in-home HEPA filters for a 2-week period (active-mode filtration) could reduce indoor $PM_{2.5}$ concentrations and improve cardio-respiratory outcome parameters compared to a 2-week control period (sham-mode filtration) in seniors with free-living in their own homes in Beijing where outdoor $PM_{2.5}$ is often high, especially in the cold months in winter.

2. Materials and methods

2.1. Study design and participants

BIAPSY is a randomized crossover intervention trial to investigate if the deployment of mobile air filtration units in private households can lead to reduction in indoor air pollution and to improve health. A panel of 35 currently non-smoking seniors from 20 households, including 15 couples and 5 single individuals, was recruited to participate in this 4-week observational intervention trial. All the study participants lived in their own homes during the study period, and had lived in Beijing for >5 years. The study participants included 20 patients with chronic obstructive pulmonary disease (COPD) and their partners, with mean age (SD) of 66.8 (7.9) years for COPD patients and 65.9 (6.9) years for non-COPD partners. The field measurements and clinical visits were conducted in the cold months between December 2013 and March 2014 in Beijing, China, when central heating was in operation. The study included two observation periods before and after the Chinese New Year holiday break, as illustrated in Fig. 1. For each study participant, repeated measurements of lung function, biomarkers of respiratory and systemic inflammation and oxidative stress were conducted at baseline, at the end of the active filtration period, and at the end of the sham filtration period. Indoor and concurrent outdoor air pollution concentrations were monitored continuously throughout the study period. Indoor air pollution concentrations were measured with several methods, including 10-day averaged $PM_{2.5}$ and black carbon (BC) concentrations representing cumulative exposures during each observational period, as well as real-