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The effects of indoor particle exposure on blood pressure and heart rate among young adults: An air filtration-based intervention study

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ABSTRACT

This study aims to evaluate whether air filtration can modify the effect of indoor particles on blood pressure (BP) and heart rate (HR) in a young, healthy population. We recruited 60 students to participate in a study of multiple, prolonged exposures to either particle-filtered or non-filtered indoor air. We made four home visits in which we took continuous 48-hour measurements of systolic BP (SBP), diastolic BP (DBP), and HR in each participant. Particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and total volatile organic compounds (VOCs) were measured at each participant's home. We used mixed-effects models to associate BP and HR with indoor particles and total VOCs, which were averaged over 1-hour to 8-hour periods prior to physiological measurements. We found that the mean values for indoor $PM_{2.5}$ exposures at 1-hour to 4-hour were associated with an elevation in SBP, DBP and HR. The effects of indoor $PM_{2.5}$ on BP and HR were greatest during the visits without air filtration. During visits with air filtration, participants showed no significant change in BP and HR in response to indoor $PM_{2.5}$ exposure. We concluded that air filtration can reduce indoor $PM_{2.5}$ concentrations and modify the effect of $PM_{2.5}$ on BP and HR in a healthy, young population.

1. Introduction

The epidemiological association of particulate matter (PM) with cardiovascular morbidity and mortality (Pope and Dockery, 1999; Pope and Dockery, 2006) has been linked to the effects of PM on elevated blood pressure (BP) and heart rate (HR), a possible mechanism linking PM to increased risk for cardiovascular diseases (Brook et al., 2010) in several panel studies (Chuang et al., 2005; Ibald-Mulli et al., 2001; Linn et al., 1999; Peters et al., 1997; Zanobetti et al., 2004). Several studies have reported the association of cardiovascular endpoints with personal exposure to PM is stronger than that with ambient PM exposure (Chuang et al., 2005; Lanki et al., 2007; Vinzents et al., 2005). Such findings imply that exposure to indoor PM might cause additional increases in cardiovascular effects. One study showed that reduction of PM exposure by filtration of recirculated indoor air improved cardiovascular health in healthy elderly subjects (Bräuner et al., 2008). However, studies of indoor air quality on cardiovascular effects among young human subjects are still lacking.

We recently found that exposure to indoor PM was associated with elevated BP and HR in a panel of healthy, young students. Closing windows could reduce indoor PM concentrations and modify the effect of indoor PM on BP and HR (Lin et al., 2009). We also found that indoor volatile organic compounds (VOCs) was associated with decreased heart rate variability in young adults (Ma et al., 2010). To follow up on the results of the previous studies in this panel, we investigated whether air filtration can reduce indoor air pollution levels and modify the adverse effects of indoor pollutants, especially fine particles ($PM_{2.5}$), on BP and HR.

2. Materials and methods

2.1. Study participants and design

As previously described (Lin et al., 2009; Ma et al., 2010), the panel study continuously monitored changes in the BP and HR of study participants and in the indoor PM and total VOC levels in participants' homes during simultaneous periods. We recruited 60 young, healthy non-smokers through an on-campus advertisement in Taipei. The protocol included four home visits that entailed continuous 48-hour BP and HR monitoring at approximately 2-week intervals between March and October 2009. Each of the 60

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participants had four home visits, making a total of 240 home visits. Four visits for each participant should be completed within 1.5-month. At each visit, a questionnaire was administered in which age, sex, body mass index (BMI), home characteristics, and time-activity patterns were noted. All participants were requested to stay home and keep their gas stoves off, windows closed and air conditioner on during visits. An air conditioner filter (Filtrete™, 3M, MN, USA) was added to participants' air conditioners in each participant's home at the last two visits. The intervention and control periods were blinded to all participants. The study design was reviewed and approved by the Human Subject Committee of St. Mary's Medicine Nursing and Management College. All participants gave written, informed consent before inclusion in the study.

2.2. BP and HR monitoring and recording

We recorded each participant's systolic BP (SBP), diastolic BP (DBP) and HR every hour during all visits using a portable BP monitoring system (DynaPulse model 5000A; Pulse Metric, San Diego, CA). Each participant carried a DynaPulse system for 48 h to complete his/her continuous BP and HR monitoring. To avoid the effects of sleep on BP and HR, we only used measurements from 07:00 AM to 11:00 PM in our data analysis. Each participant yielded approximately 128 successful BP and HR measurements over four visits (32 measurements per visit).

2.3. Indoor air pollution and indoor climate data

A detailed description of the sampling procedures and data validation is given in our previous study (Lin et al., 2009). In brief, a portable dust monitor (DUST-check portable dust monitor, model 1.108; Grimm Labortechnik Ltd., Ainring, Germany), which recorded 1-min mass concentrations of $PM_{2.5}$ and 1-min measurements of temperature and humidity, was placed in each participant's home during the study period. Exposure to total volatile organic compounds (VOCs) was also continuously measured using a total VOC monitor (ppbRAE Plus, model PGM-7240; RAE Systems, Inc., San Jose, CA). After converting the 1-min $PM_{2.5}$ and 1-min total VOC concentrations between 07:00 AM and 11:00 PM to hourly means, we obtained approximately 128 measurements of $PM_{2.5}$, temperature and humidity for each participant (32 measurements per visit).

2.4. Statistical analysis

To compare BP, HR, $PM_{2.5}$, total VOCs, temperature and humidity during each visit, a one-way analysis of variance (ANOVA) with Scheffe's mean comparison test was used. Linear mixed-effects regression models were applied to examine the association between indoor $PM_{2.5}$, BP, and HR in young adults by running S-PLUS 2000 (MathSoft Inc., Cambridge, MA, USA). The outcome variables were SBP, DBP, and HR, and the exposure variable was $PM_{2.5}$ at 1- to 8-hour means. Each regression model included fixed effects for age, sex, BMI, usage of the air conditioner filter (yes or no), day of the week, visit order, and random effects for participant-specific terms. The models also adjusted for several smooth function terms fit by nature spline. These terms included hour of the day, temperature and humidity. Estimates of the effects of indoor $PM_{2.5}$ were scaled to interquartile range (IQR), the difference between the 25th and the 75th percentile, in levels for the appropriate hour mean of indoor $PM_{2.5}$.

3. Results

Sixty young adults were recruited for this study, and 240 home visits with 7680 hourly physiological measurements were included in data analyses. The median age of the population was 25.0 years (SD = 2.3 year), the average BMI was 24.1 kg m^{-2} (SD = 2.9 kg m^{-2}), and the male-to-female ratio was 1:1. None of the participants had cardiopulmonary disease, took medication, or were exposed to tobacco smoke. The average air change rate and air flow velocity of the air conditioner in participant's home were 1.6 ACH and 7.8 m s^{-1}, respectively. The average distance between the air conditioner and indoor air pollution monitor was 10 m.

Table 1
Summary statistics for mean hourly BP, HR, indoor particle concentrations, temperature, and humidity, averaging over 1920 total measurements per visit for the 60 study participants.

	First visit (without filter)	Second visit (without filter)	Third visit (with filter)	Fourth visit (with filter)	ANOVA	
					p-Value	Scheffe's test
SBP, mmHg						
Mean ± SD	126.0 ± 23.7	120.2 ± 22.8	110.9 ± 22.4	108.4 ± 21.5	<0.05	1st/3rd; 1st/4th;
Range	81.0–163.0	73.0–155.0	71.0-144.0	70.0–142.0		2nd/3rd; 2nd/4th
DBP, mmHg						
Mean ± SD	84.6 ± 20.1	85.8 ± 23.4	79.6 ± 22.0	77.5 ± 20.6	<0.05	1st/3rd; 1st/4th;
Range	62.0–130.0	55.0–139.0	48.0–114.0	51.0–110.0		2nd/3rd; 2nd/4th
HR, beats min^{-1}						
Mean ± SD	82.5 ± 7.0	78.7 ± 7.2	71.1 ± 6.0	72.6 ± 6.3	<0.05	1st/3rd; 1st/4th;
Range	66.0–96.0	63.0–91.0	60.0–84.0	61.0–85.0		2nd/3rd; 2nd/4th
$PM_{2.5}$, μg m^{-3}						
Mean ± SD	22.8 ± 12.2	24.5 ± 13.0	17.3 ± 8.0	18.8 ± 8.9	<0.05	1st/3rd; 2nd/3rd;
Range	5.1–60.0	6.5–70.5	5.6–39.8	6.5–56.2		2nd/4th
Total VOCs, μg m^{-3}						
Mean ± SD	40.1 ± 17.2	42.0 ± 16.1	36.5 ± 13.8	38.6 ± 12.5	0.69	–
Range	2.5–95.0	6.0–105.5	4.6–86.7	7.3–79.0		
Temperature, °C						
Mean ± SD	23.2 ± 1.2	24.0 ± 1.1	23.7 ± 1.0	24.0 ± 1.3	0.76	–
Range	21.0–25.5	22.0–25.8	22.2–24.9	21.4–25.2		
Relative humidity, %						
Mean ± SD	55.0 ± 6.5	54.3 ± 7.0	54.9 ± 6.8	55.4 ± 7.2	0.69	–
Range	45.5–75.0	40.7–70.5	45.1–74.6	44.0–73.0		

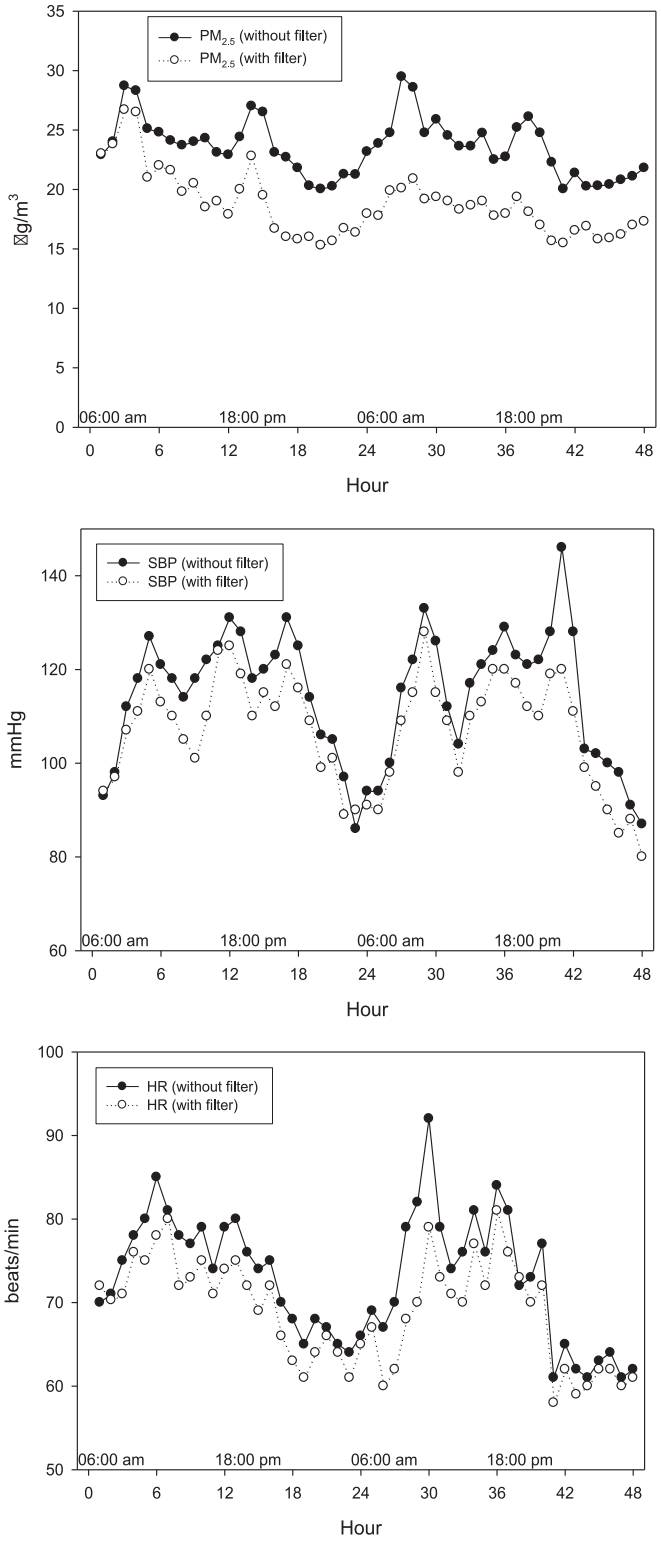

Fig. 1. Arithmetic mean of hourly levels of particulate matter less than 2.5 μm in diameter ($PM_{2.5}$), systolic blood pressure (SBP), and heart rate (HR) during the visits without filter and the visits with filter.

Table 1 summarizes BP, HR, indoor particles and indoor climate data over 1920 total measurements per visit for the 60 participants. The BP and HR were within the normal range (Chobanian et al., 2003; Limmer et al., 2005). Participants had higher indoor $PM_{2.5}$ exposures and higher BP and HR responses during the first two visits (without the air conditioner filter) compared to the last two visits (with the air conditioner filter) (ANOVA, p-value < 0.05). There were no significant differences in indoor temperature and humidity between the four visits; the indoor climate was pleasant, with a temperature of 21.0 to 25.8 °C and a relative humidity of 40.7–75.0% during visits.

Table 2
Changes (95% confidence interval) in BP and HR for interquartile range changes in indoor $PM_{2.5}$[a] estimated by mixed-effects models.

	Exposure matrix	Systolic blood pressure (mmHg)	Diastolic blood pressure (mmHg)	Heart rate (beats min^{-1})
$PM_{2.5}$	1-hour mean	1.83 (0.35, 3.31)	1.34 (0.15, 2.54)	1.99 (1.10, 1.89)
	2-hour mean	2.40 (0.72, 4.08)	2.12 (0.89, 3.35)	2.10 (1.46, 2.74)
	4-hour mean	3.15 (1.23, 5.07)	2.67 (1.02, 4.32)	3.88 (1.89, 5.88)
	8-hour mean	0.14 (−2.17, 2.45)	−0.55 (−1.67, 0.57)	1.01 (−0.54, 2.55)

[a] The interquartile range of $PM_{2.5}$ at 1- to 4-hour means were 23.2, 21.6, 19.7, and 19.0 μg m^{-3}.

Fig. 1 depicts mean hourly levels of indoor $PM_{2.5}$, SBP, and HR during visits without and with the filter. Levels of indoor $PM_{2.5}$ rose early in the morning at 04:00 AM and peaked at 08:00 AM during the visits without the air conditioner filter; in contrast, levels of indoor $PM_{2.5}$ were relatively stable during the visits with the air conditioner filter. Similar patterns were found in SBP and HR. Pearson correlations showed moderate correlations between indoor $PM_{2.5}$ levels ($r = 0.59$, p-value < 0.01) during the visits without the filter and the visits with the filter.

The associations between indoor $PM_{2.5}$, BP, and HR, estimated by mixed-effects models, are shown in Table 2. After adjusting for age, sex, BMI, usage of the air conditioner filter, day of the week, and visit order in our mixed-effects models, we found that an IQR increased the mean 1- to 4-hour $PM_{2.5}$ levels and predicted the elevation of hourly averaged BP and HR. For BP, SBP increased by 1.83–3.15 mmHg per IQR of $PM_{2.5}$ at 1- to 4-hour means (23.2, 21.6, 19.7, and 19.0 μg m^{-3}). Likewise, DBP increased by 1.34–2.67 mmHg per IQR of $PM_{2.5}$ at the 1- to 4-hour means. Elevations in HR of 1.99–3.88 beats min^{-1} were also observed in response to IQR changes of the 1- to 4-hour mean $PM_{2.5}$. Indoor total VOC exposure was not associated with BP and HR elevation in our participants.

We performed an effect modification of association for indoor $PM_{2.5}$ exposure with BP and HR by usage of the air conditioner filter (Table 3) and found a consistent effect modification of indoor $PM_{2.5}$ with filter usage. During visits without filter usage, participants' SBP, DBP, and HR increased by 4.11 mmHg, 2.78 mmHg and 3.11 beats min^{-1} per IQR of $PM_{2.5}$ at the 4-hour mean, respectively. During the visits with filter usage, participants showed no

Table 3
The effect modification of association of indoor $PM_{2.5}$ exposure with BP and HR by air conditioner filter usage.

	Air conditioner filter using		
	Yes	No	*P* value, interaction
Systolic blood pressure, mmHg			
4-hour mean $PM_{2.5}$ (95% CI)	4.11 (2.21, 6.00)*	−1.02 (−2.02, 0.03)	<0.01
Diastolic blood pressure, mmHg			
4-hour mean $PM_{2.5}$ (95% CI)	2.78 (1.45, 4.10)*	−0.32 (−0.99, 0.35)	<0.01
Heart rate, beats min^{-1}			
4-hour mean $PM_{2.5}$ (95% CI)	3.11 (1.89, 4.33)*	0.67 (−0.20, 1.55)	<0.05

* p-Value < 0.05.

significant change in BP (interaction P value < 0.01) and HR (interaction p-value < 0.05).

4. Discussion

Our results suggest that indoor $PM_{2.5}$ levels can lead to elevated HR and BP, which are risk factors for cardiovascular morbidity and mortality (Chobanian et al., 2003; Walldius et al., 2001). Increases in participants' BP and HR due to indoor $PM_{2.5}$ were consistent with our previous findings (Lin et al., 2009). Zanobetti et al. (2004) found a greater effect of ambient $PM_{2.5}$ on SBP and DBP (2.8/2.7 mmHg increase in SBP/DBP per 10.5 $\mu g\, m^{-3}$ ambient $PM_{2.5}$ at 5-day mean) in cardiac rehabilitation patients than we did for indoor $PM_{2.5}$ (3.15/2.67 mmHg increase in SBP/DBP per 19.0 $\mu g\, m^{-3}$ indoor $PM_{2.5}$ at 4-hour mean) in our study. Chuang et al. (2005) showed a 3.4 mmHg increase in SBP, a 2.2 mmHg increase in DBP, and a 1.2 beats min^{-1} increase in HR among patients with lung function impairments, for increases of 10,000 particles cm^{-3} in ambient submicrometer particles (PM less than 1 μm in diameter) at 2-hour mean. These findings on ambient PM were more dramatic than the effects of indoor PM observed in this study. Although comparisons can only be indirect, these findings also imply that young adults are less susceptible to PM exposure.

Modulation of the autonomic nervous system plays an important role in hypertension and the alteration of BP and HR (Grassi, 1998; Malpas, 1998). Our findings on the effects of indoor PM exposure on BP and HR (Lin et al., 2009), and the associations between ambient PM on BP and HR reported in our previous study (Chuang et al., 2005), suggest that PM can have adverse effects on cardiac autonomic function in human subjects. Studies have also shown that PM-induced vascular endothelial perturbation (Bouthillier et al., 1998) and systemic inflammation (Peters et al., 1997; Schwartz, 2001) can occur hours or even days after exposures and then alter sympathetic nerve activity and BP (Nakamura et al., 1999) in human subjects or experimental animals. Moreover, some studies have shown that inhaled particles can rapidly pass into the blood circulation of human subjects and experimental animals in a few minutes and cause adverse cardiovascular effects directly after exposures (Nemmar et al., 2001, 2002). Accordingly, we believe indoor PM-induced systemic inflammation could result in BP and HR changes after indoor PM exposures.

The most interesting finding of this study was that usage of an air conditioner filter seemed to modify the indoor PM effects on BP and HR; greater indoor PM effects on BP and HR were observed during visits without air conditioner filters compared to those during the visits with air conditioner filters. These findings imply that exposure to indoor particles was associated with increased BP and HR. Indoor air filtration could reduce indoor PM concentrations and modify the effect of $PM_{2.5}$ on BP and HR in young adults in Taipei, Taiwan. An association between total VOCs and BP or HR was not found in this study. This result is unsurprising, as the filtration of indoor air had no effect on the level of total VOCs. The association between indoor $PM_{2.5}$ and the increases in BP and HR found in the study could be confounded by the unavailability of data on the indoor exposure to other air pollutants. The lack of indoor exposure to ozone and the specific compositions of the particles, including their elemental and soluble ionic contents, may still confound the observed associations between indoor PM and increases in BP and HR.

5. Conclusions

Regardless of these limitations, we believe our data generally support the idea that changes in indoor $PM_{2.5}$ can lead to increases in BP and HR. Reduction of indoor particles in the home by air filtration can thus improve autonomic function in a panel of healthy, nonsmoking, young students.

The effects we observed in this study were measured after 4- to 8-hour interventions. Further studies are needed to determine whether long-term intervention, over weeks to months, will have meaningful implications for cardiovascular morbidity and mortality in this healthy, young age group.

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