Building and Environment 126 (2017) 266–275

Contents lists available at ScienceDirect

Building and Environment

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

Lessons from in-home air filtration intervention trials to reduce urban ultrafine particle number concentrations

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ARTICLE INFO

Keywords:
Urban air pollution
Air filtration
HEPA
Ultrafine particles
Intervention
Puerto Rican
Community-based

ABSTRACT

Background: Exposure to airborne ultrafine particle (UFP; < 100 nm in aerodynamic diameter) is an emerging public health problem. Nevertheless, the benefit of using high efficiency particulate arrestance (HEPA) filtration to reduce UFP concentrations in homes is not yet clear.

Methods: We conducted a randomized crossover study of HEPA filtration without a washout period in 23 homes of low-income Puerto Ricans in Boston and Chelsea, MA (USA). Most participants were female, older adults who were overweight or obese. Particle number concentrations (PNC, a proxy for UFP) were measured indoors and outdoors at each home continuously for six weeks. Homes received both HEPA filtration and sham filtration for three weeks each in random order.

Results: Median PNC under HEPA filtration was 50–85% lower compared to sham filtration in most homes, but we found no benefit in terms of reduced inflammation; associations between hsCRP, IL-6, or TNFRII in blood samples and associations with indoor PNC were inverse and not statistically significant.

Conclusions: Limitations to our study design likely contributed to our findings. Limitations included carry-over effects, a population that may have been relatively unresponsive to UFP, reduction in PNC, even during sham filtration, that limited differences between HEPA and sham filtration, window opening by participants, and lack of fine-grained (room-specific) participant time-activity information. Our approach was similar to other recent HEPA intervention studies of particulate matter exposure and cardiovascular risk, suggesting that there may be a need to improve study designs.

1. Background

While exposure to ambient airborne particulate matter < 2.5 μm in aerodynamic diameter ($PM_{2.5}$) is one of the top ten causes of morbidity and mortality worldwide [1], less is known about health effects from smaller particles, such as ultrafine particles (UFP; < 0.1 μm in aerodynamic diameter), which are abundant in combustion emissions. In the U.S., $PM_{2.5}$ is regulated by the EPA and is considered a regional pollutant because its concentration is relatively uniform over large distances (tens-to -hundreds of km). In contrast, UFP (that are primarily of traffic emission origin in urban areas) are quite variable over much shorter distances (tens-to-hundreds of m) [2,3], are unregulated, and may represent an independent health burden. Furthermore, evidence from animal studies [4] and from observational epidemiology suggests that UFP are associated with indicators of CVD risk as well as adverse health outcomes [5–8].

While increasing outdoor air brought into buildings has traditionally been associated with improved health [9], there is convincing evidence that living close to outdoor sources such as major roadways and highways is associated with elevated cardiovascular disease (CVD) and respiratory disease risk [10,11]. UFP have been shown in many studies to also be elevated in these locations [3]. Accordingly, there is increasing interest in using air filtration to reduce exposure to urban UFP in both schools and homes. For example, recently a requirement

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http://dx.doi.org/10.1016/j.buildenv.2017.10.007
Received 12 July 2017; Received in revised form 3 October 2017; Accepted 4 October 2017
Available online 06 October 2017
0360-1323/

Table 1
Participant demographics.

Category	BPRHS			Somerville			Combined		
	Total (n = 23)	HEPA First (n = 11)	Sham First (n = 12)	Total (n = 20)	HEPA First (n = 10)	Sham First (n = 10)	Total (n = 43)	HEPA First (n = 21)	Sham First (n = 22)
Demographic Data									
Age, Mean (min-max), years	64.1 (52–78)	63.6 (52–73)	64.5 (55–78)	52.9 (42–79)	55.3 (42–79)	50.6 (42–63)	58.9 (42–79)	59.6 (42–79)	58.1 (42–78)
BMI, Median (Min-Max)	31.6 (24.4–49.9)	32.5 (24.4–42.6)	29.9 (25.5–49.9)	33.2 (20–72)	33.6 (20–72)	32.9 (25–51)	32.9 (20–72)	33.03 (20–72)	32.9 (25–51)
Female	18 (78%)	8 (73%)	10 (83%)	16 (80%)	7 (70%)	9 (90%)	34 (79%)	15 (71%)	19 (86%)
Hispanic	23 (100%)	11 (100%)	12 (100%)	7 (35%)	3 (30%)	4 (40%)	30 (70%)	14 (67%)	16 (73%)
Annual Household Income < $24,999	19 (83%)	8 (73%)	11 (92%)	15 (75%)	9 (90%)	6 (60%)	34 (79%)	17 (81%)	17 (77%)
Annual Household Income $25,000–$74,999	1 (4%)	1 (9%)	0 (0%)	3 (15%)	1 (10%)	2 (20%)	4 (9%)	2 (10%)	2 (9%)
Eighth Grade Education	9 (39%)	4 (36%)	5 (42%)	13 (65%)	5 (50%)	8 (80%)	22 (51%)	9 (43%)	13 (31%)
Below Federal Poverty Threshold[a]	12 (52%)	4 (36%)	8 (67%)						
Employed	0 (0%)	0 (0%)	0 (0%)	9 (45%)	3 (30%)	6 (60%)	9 (21%)	3 (14%)	6 (27%)
Distance to I-93: ≤100 m[a]				10 (50%)	6 (60%)	4 (40%)			
Distance to I-93: 101–200 m[a]				10 (50%)	4 (40%)	6 (60%)			
< 50 m to a major roadway[a]	7 (32%)	3 (30%)	4 (33%)						
Health data and Medicines used									
Total Cholesterol, mean (min-max), mg/dL	207.3 (147–307)	197.8 (147–307)	220.4 (178–255)	290.2 (100–450)	263.6 (100–400)	316.9 (141–450)	249.8 (100–450)	229.1 (100–400)	274 (141–450)
Triglycerides, mean (min-max), mg/dL	192 (75–610)	187.3 (93–425)	198.4 (75–610)	211.4 (50–500)	169 (50–375)	253.9 (50–500)	202 (50–610)	178.6 (50–425)	229.2 (50–610)
Previous Heart Attack	8 (36%)	5 (50%)	3 (25%)	1 (5%)	1 (10%)	0 (0%)	9 (21%)	6 (30%)	3 (14%)
Diabetes	12 (52%)	8 (73%)	4 (33%)	2 (10%)	0 (0%)	2 (20%)	14 (33%)	8 (38%)	6 (27%)
High Blood Pressure or Hypertension	18 (82%)	8 (80%)	10 (83%)	11 (55%)	8 (80%)	3 (30%)	29 (69%)	16 (80%)	13 (59%)
Anti-hypertension medicine	18 (78%)	9 (82%)	9 (75%)	10 (50%)	7 (70%)	3 (30%)	28 (65%)	16 (76%)	12 (55%)
Anti-inflammatory medicine	4 (17%)	2 (18%)	3 (25%)	7 (35%)	6 (60%)	1 (10%)	11 (26%)	8 (38%)	4 (18%)
Anti-lipids medicine	17 (74%)	10 (91%)	7 (58%)	3 (15%)	2 (20%)	1 (10%)	20 (47%)	12 (57%)	8 (36%)
Anti-diabetes medicine	11 (48%)	8 (73%)	3 (25%)	3 (15%)	1 (10%)	2 (20%)	14 (33%)	9 (43%)	5 (23%)
Window Opening									
Window opening during December to February	8 (35%)	6 (55%)	2 (17%)	9 (45%)	4 (40%)	5 (50%)	17 (40%)	10 (48%)	7 (32%)
Window opening during June to August	16 (70%)	8 (73%)	8 (67%)	17 (85%)	9 (90%)	8 (80%)	33 (77%)	17 (81%)	16 (73%)

[a] Demographic data only recorded for one study.

for high-grade filtration in schools and homes near highways was enacted in Los Angeles [12]. While several studies have shown that filtration in mechanical air handling systems can reduce indoor UFP relative to outdoors [13,14], it has been more difficult to reduce indoor UFP, especially in low-income households, that lack mechanical ventilation [2,15]. To date, few studies have evaluated the health benefits of reducing indoor concentrations of urban UFP [16,17].

We conducted a randomized crossover trial of air filtration in homes of low-income Puerto Rican residents in Boston and Chelsea, MA (USA). The intervention was a collaboration between the Community Assessment of Freeway Exposure and Health study (CAFEH; [18]) and the Boston Puerto Rican Health Study (BPRHS; [19]). In addition to the trial results, we conducted a meta-analysis with a second in-home HEPA intervention trial conducted in nearby Somerville, MA as part of CAFEH [17]. Our goals were to measure changes in indicators of cardiovascular health due to in-home air filtration and to provide guidance for emerging public health efforts that reduce exposure to urban pollution.

2. Methods

We hypothesized 1) that high efficiency particulate arrestance (HEPA) filtration in homes would reduce UFP concentrations indoors more than sham filtration and 2) that reduced UFP concentrations would lead to reductions in biomarkers of inflammation for residents. The study was a double-blind, randomized crossover trial in which each participant served as their own control, thereby greatly reducing the role of time-invariable confounders. Up to two homes were enrolled and randomized at a time, with one allocated to receive HEPA filtration and the other sham filtration first. At three weeks, the homes were switched from HEPA filtration to sham or vice versa. There was no washout period between sham and HEPA filtration. While field staff were aware of the type of filter in use, the participants and the lab that analyzed blood samples were not. The approach and methods were largely similar to another HEPA intervention we conducted in public housing in the City of Somerville, which was still in progress at the start of this study [17].

Participants were recruited from the BPRHS cohort. The parent study was in the process of follow-up at approximately five years since baseline with close to 1000 participants remaining. The cohort staff recommended non-smoking participants who they thought might be receptive to our intervention. Of the 25 participants enrolled, 23 (92%) completed the study and were included in the analysis. One home was removed due to the failure of the flow sensor, which identified indoor versus outdoor air, while the other was removed because the participant opted to end the study early. All participants lived in the cities of Boston or Chelsea. Data on demographics and health were obtained from surveys collected during longitudinal follow-up of the cohort. For the participants receiving the intervention, we collected additional surveys with information on recent exposures, and recent illnesses.

Participants signed consent forms for the parent study and a separate consent for the air filtration intervention. The studies were approved by the IRBs at Tufts Medical Center, Northeastern University, and the University of Massachusetts Lowell.

Window-mounted HEPAiRx air filtration units (Air Innovations,