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Reaction to at-home air purifiers installed to reduce traffic-related air pollution in near-highway residences

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Abstract

Background and aim Traffic-related ultrafine particle pollution near highways is associated with adverse health. Reducing exposure by use of portable air purifiers in homes is one approach to reducing this risk. However, the reaction of residents to having air purifiers in homes is not well studied.

Methods Within the framework of our randomized crossover trial of air purifiers in homes near a major highway, we collected data about participants' use and reactions to air purifiers using questionnaires at their 30-day and 90-day home visits, recorded electricity consumption using HOBO monitors, and conducted structured interviews with participants.

Results Nearly all 150 participants reported running the air purifiers virtually 24 h every day in both their living room and their bedroom in the prior month. The units' HOBO electricity use, from a subset of 45 participants, supported the participants' responses from the questionnaire. Approximately 80% of participants reported setting their air purifier on the medium setting. Tolerance to air purifier noise increased significantly between the 30-day and 90-day home visits, with approximately two thirds reporting not being bothered at all by the noise. The qualitative interviews in a subset of 26 participants yielded consistent responses to those from the questionnaires. Size of unit, airflow, and energy consumption were additional concerns that emerged during the interviews.

Conclusions Results from the questionnaires, HOBO data, and structured interviews all suggest participants had positive reactions towards the presence of in-home APs, and therefore may be receptive to using air purifiers in their homes on a regular basis.

Trial registration ClinicalTrials.gov, NCT04279249. Registered 09 October 2019.

Keywords Air purifiers, Acceptability, Traffic-related air pollution, Ultrafine particulates, Clinical trials

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Introduction

Air pollution is a major public health concern in the United States and across the globe. According to the World Health Organization, 99% of the global population inhales air that exceeds their guidelines [1]. These pollutants can be gaseous, or can contain solid components known as particulate matter (PM) [1]. PM varies in size, surface area, chemical composition, and concentration and is often classified by aerodynamic diameter [2]. The two smallest categories are fine particles, with a diameter < 2.5 µm ($PM_{2.5}$), and ultrafine particles, with a diameter < 0.1 µm (UFP) [2].

A primary outdoor (ambient) source of UFPs is traffic-related air pollution (TRAP), which, in the urban areas of developed countries, is the predominant contributor to poor air quality. In the United States, around 4% of the population live within 150 m of a major highway and are therefore frequently exposed to elevated levels of UFPs from TRAP [3].

PM is associated with adverse human health effects. It is estimated that over nine million deaths globally are associated with exposure to $PM_{2.5}$ alone [4]. Conditions linked to PM exposure include asthma, adverse cardiovascular outcomes, chronic obstructive pulmonary disease, lung cancer, and premature mortality [5–8]. As one of the top ten causes of morbidity and mortality worldwide, exposure to PM is a public health problem that requires protective interventions [9]. Despite the established link between PM and adverse health outcomes, there have been relatively few efforts to assess the benefits of reducing PM exposure. Research is needed on how to achieve reductions in PM and achieve health benefits in near-highway households that lack centralized air handling systems with filtration.

Current measures to reduce air pollution include the use of air purifiers (APs) containing high-efficiency particulate arrestance (HEPA) filters [10]. HEPA filtration has been shown to reduce both $PM_{2.5}$ and UFP. Some studies have reported 45–69% PM reduction after 90 min of filtration, with higher fan speeds correlated with greater reduction in PM [11]. Studies have also reported that closing windows and doors increases airflow through the filtration system and results in greater improvement in air quality, whereas opening windows and doors reduces improvements in air quality [12]. Considering people do not readily perceive PM as affecting air quality, the continual use of air filtration devices is important to protect against elevated PM levels and the associated health effects [11, 13].

APs are associated with health benefits. For example, APs may produce respiratory benefits by improving allergic airway disease in children, as well as reducing triggers for asthma among adults and children [14, 15]. Additionally, APs may improve circulatory and cardiorespiratory health in both older adults and young healthy adults by lowering blood pressure and systemic oxidative stress, and improving lung function [16]. During the COVID-19 pandemic, air filtration became more popular in homes, schools, and offices as a strategy to control the transmission of COVID-19 [17, 18].

There is a need to explore how resident behavior affects use and efficacy of APs, as their theoretical benefit can be compromised if they are not used optimally, or at all. Portable APs can be easily installed, do not require a centralized air handling system, and are portable [5], all of which may contribute to their acceptability and eventual adoption. To date, however, the few studies that have investigated participants' attitudes, behavior, and experiences with air purifiers have had varied results [5, 10, 11, 19, 20]. This study fills a gap in the literature by reporting participants' reactions in using portable home APs to reduce TRAP exposure.

Materials and methods

Data collection

Data for the present study were derived from the Home Air Filtration for Traffic-Related Air Pollution (HAFTRAP) study, which is a double-blind, randomized crossover trial of in-home HEPA air filtration to reduce UFP exposure in Somerville, MA, USA. The study was approved by the University of Connecticut, School of Medicine IRB. A description of the design and methods has been published [21].

In brief, households were randomized to 30 days of either HEPA filtration or sham filtration, with AP units placed in the living room and bedroom, followed by a 30-day washout period, and then a subsequent 30-day period of the alternative intervention. We installed freestanding, custom-made HealthMate air purifiers manufactured by Austin Air (Buffalo, NY) with or without high efficiency particulate air (HEPA) filters for the sham configuration. Biological measures were collected, and questionnaires were administered at trial entry and subsequently at 30, 60, and 90 days. The primary health outcome for the trial was peripheral systolic blood pressure (SBP), based on our prior findings from a controlled exposure study showing a reduction in SBP with decreased PM. Secondary outcomes were diastolic and central BP and blood biomarkers for inflammation, also based on prior findings [22]. A sample size of 207 participants had been calculated to detect a 2.5-mmHg mean difference in peripheral systolic blood pressure between HEPA and sham filtration [21]. Although air purifiers like the ones used in this study typically cost $500–$1000, there were no purchasing or installation charges for the participants in the trial period. Additionally, to compensate for the cost of electricity consumption, participants received $100 worth of gift cards.

The trial enrolled individuals who were 30 years of age or older, lived full time at their house in Somerville MA within 200 m of the highway, had cognitive capacity to fill out questionnaires, and spoke English or Spanish. Recruitment was by door-to-door canvassing, email lists, outreach at events and referral by previous participants. The trial excluded entry to individuals who currently smoked/vaped or lived with indoor smokers/vapers because air purifiers are ineffective against indoor secondhand smoke. We also excluded those with a history of heart attack, stroke, or other major cardiovascular event and were currently taking anti-hypertensive or anti-inflammatory medications. Each of these health conditions is likely to overwhelm the effects of air pollution on one or more of our health endpoints. Additionally, participants were not enrolled if they had occupational or regular exposures to traffic pollution outside of the home or significant combustion sources inside the home [21]. Data were collected between September and June, with the intent to have participants during cooler months when the levels of ultrafine particulate matter tend to be higher.

Three sources of data were used for the present mixed methods study. Data triangulation involved the primary author comparing and contrasting the findings from across each data source and meeting with the second and fifth author to discuss patterns in the context of the qualitative data. The purpose for triangulating data from three different sources was to cross-check participant responses and therefore increase credibility and validity of the study results [23]. Data sources were given equal weight, rather than prioritizing one source over the other. We sought to tell a holistic story about participant experiences with and reactions to APs. A flowchart of the data collection process is shown in Fig. 1.

The first source of data were responses to follow-up questionnaires administered to all participants at their 30-day and 90-day home visits. The questionnaires contained 35 questions total, but only 11 questions related to the participants' reactions to the air purifiers, asking how they used the APs during the past 30 days in both their living room and bedroom, and to what extent they were affected by noise produced by the APs. These questions were custom-designed and tailored for this study. Each question is listed in Tables 2 and 3. Data collection occurred monthly and was conducted by a phlebotomist and the project manager of the study.

The second source of data was from a subset of participants who had a HOBO Plug Load Data Logger installed between their air purifier and electrical outlet. Though all participants were informed from the beginning about the different subsets they could opt into during the different

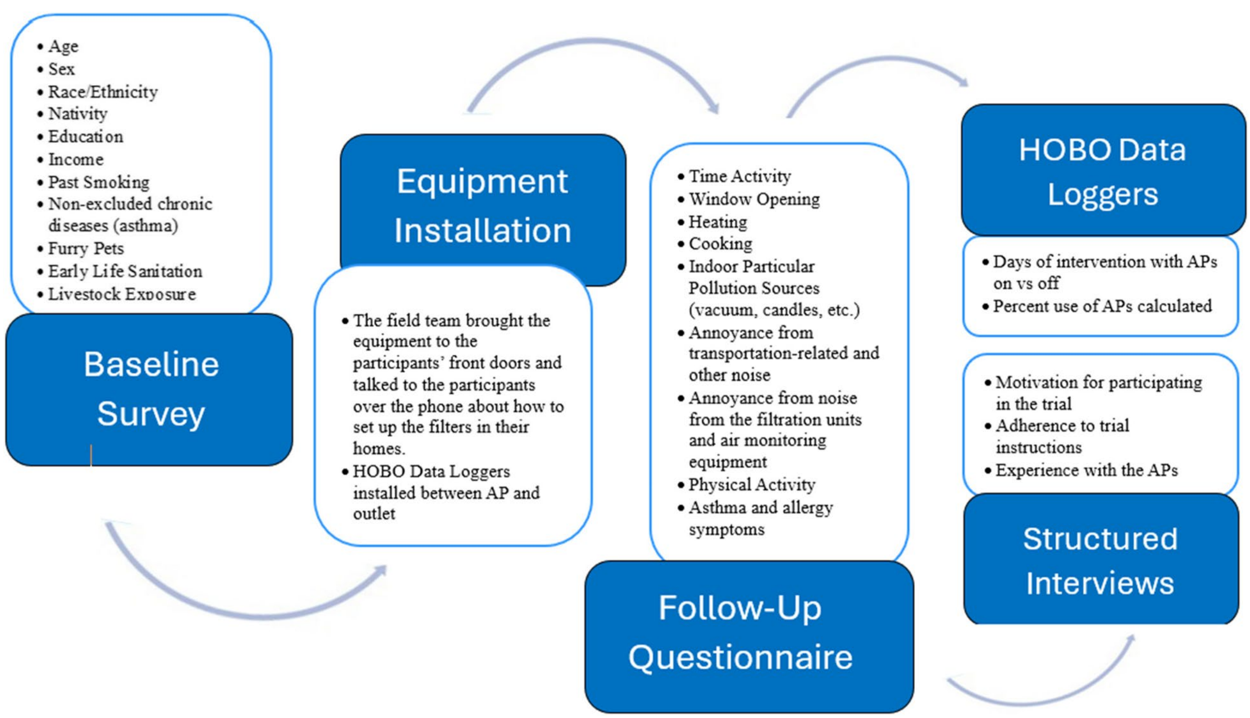

Fig. 1 Flowchart of study process

months of the study, the subsets were ultimately selected on a participant-by-participant basis, according to participant interest and availability. The purpose of the HOBO Data Logger was to continuously record electricity use to determine when the APs were on versus off, which was then used to calculate the percentage of time the air purifiers were running over the past 30 days.

Finally, structured interviews with a subset of participants were conducted. Again, this subset was selected on a participant-by-participant basis depending on interest and availability. One member of each household enrolled in the study was contacted and invited to participate in a structured qualitative telephone interview. Interviews explored participant motivation for participating in the trial, adherence to trial instructions, and experience with the APs. The interviews lasted an average of 15–20 min. Data collection was continued until saturation was achieved. Responses were recorded by the interviewer in Qualtrics; short answers captured verbatim and read back to the participant to ensure accuracy of the response.

Data analyses

Data were summarized using means with standard deviations for continuous data and were summarized using frequencies with percentages for categorical data. Generalized linear models (GLM) with generalized estimating equations (GEE) were used to compare participant-reported outcomes between the 30-day and 90-day home visits. GEEs, using an exchangeable correlation structure, account for the within-participant correlation between the 30-day and 90-day outcomes. GLMs for continuous outcomes were fit with a normal distribution and identity link, GLMs for ordinal outcomes were fit with a multinomial distribution and cumulative logit link, and GLMs for binary outcomes were fit with a binomial distribution and logit link. All statistical analyses were carried out using SAS 9.4 (SAS Institute Inc., Cary, NC), and results with p-values < 0.05 were deemed statistically significant. Short answers from interviews were exported in Excel, and thematic analysis was employed following the six steps outlined by Braun and Clark (2006) to identify patterns in the data. Coders immersed themselves in the data, developed codes, identified and refined themes, and selected specific examples [24].

Results

Quantitative results

Of the 156 participants who were enrolled into the trial between November 2020 and March 2024, 6 (3.84%) did not complete either their 30-day or 90-day follow-up questionnaires. The demographic characteristics of the remaining 150 participants are presented in Table 1. The average age was 41 years old, and more than half of participants were female. Two thirds of participants were of white, non-Hispanic race. Most participants had either a college degree or higher and worked full time.

Table 1 Demographic characteristics of participants

	(*n* = 150)
Age in years, mean (standard deviation)	41.3 (10.3)
Sex, *n* (%)	
Male	60 (40.0)
Female	87 (58.0)
Non-binary	3 (2.0)
Ethnicity and race, *n* (%)	
Hispanic	28 (18.7)
White, non-Hispanic	100 (66.7)
Black, non-Hispanic	8 (5.3)
Asian, non-Hispanic	12 (8.0)
Other, non-Hispanic	2 (1.3)
Highest level of education, *n* (%)	
Grade or high school	17 (11.3)
Some college	18 (12.0)
College or university degree	40 (26.7)
Graduate degree	75 (50.0)
Work status, *n* (%)	
Unemployed	27 (18.0)
Part-time working	17 (11.3)
Full-time working	106 (70.7)
Total annual household income, *n* (%)	
< $48,000	11 (7.3)
$48,000 to $84,999	17 (11.3)
$85,000 or greater	95 (63.4)
Declined to answer	27 (18.0)

No changes in participant use of APs were reported between their 30-day and 90-day home visits (Table 2). At both visits, nearly all participants had APs running virtually 24 h every day in both their living room and their bedroom in the prior month. Approximately 80% of participants reported running the AP on the medium setting and approximately 10% running on the high setting. Very few participants used the low setting.

A significant increase in noise tolerance was reported by participants (Table 3). Whereas approximately one half of participants reported not being bothered, disturbed, or annoyed by the AP's noise in the living room at the 30-day visit, approximately two thirds reported not being bothered at the 90-day visit (p-value ≤ 0.001). A significant increase in noise tolerance was also reported regarding the AP in the bedroom (p-value = 0.001). A small percentage (approximately 10%) of participants reported the APs bothering, disturbing, or annoying the participant at the 30-day visit, which was reduced

Table 2 Participant-reported use of air purifiers

Question asked on the questionnaire	30-day home visit ($n = 150$)	90-day home visit ($n = 150$)	*p*-value
During the last month, how often did you have the living room filter running? *n* (%)			
Every day	148 (98.7)	148 (98.7)	1.00
A few times a week	2 (1.3)	2 (1.3)	
On days you had the living room filter running for about how many hours was it on?			
Mean (standard deviation)	23.8 (1.7)	23.8 (1.7)	1.00
When running, what setting was the living room filter usually on? *n* (%)			
High	14 (9.3)	15 (10.0)	0.45
Medium	126 (84.0)	127 (84.7)	
Low	10 (6.7)	8 (5.3)	
During the last month, how often did you have the bedroom filter running? *n* (%)			
Every day	149 (99.3)	149 (99.3)	1.00
A few times a week	1 (0.7)	1 (0.7)	
On days you had the bedroom filter running for about how many hours was it on?			
Mean (standard deviation)	23.9 (1.3)	23.9 (1.3)	1.00
When running, what setting was the bedroom filter usually on? *n* (%)			
High	15 (10.0)	12 (8.0)	0.68
Medium	121 (80.7)	125 (83.3)	
Low	14 (9.3)	13 (8.7)	

Table 3 Participant-reported perception of noise

Question asked on the questionnaire	30-day home visit ($n = 150$)	90-day home visit ($n = 150$)	*p*-value
Thinking about the last week when you are here at home, how much does noise from the following bother, disturb or annoy you:			
Living room air filtration unit? *n* (%)			
Not at all	78 (52.0)	101 (67.4)	< 0.001
Slightly	56 (37.3)	42 (28.0)	
Moderately	15 (10.0)	5 (3.3)	
Very or extremely	1 (0.7)	2 (1.3)	
Bedroom air filtration unit? *n* (%)			
Not at all	91 (60.7)	108 (72.0)	0.001
Slightly	41 (27.3)	32 (21.3)	
Moderately	15 (10.0)	9 (6.0)	
Very or extremely	3 (2.0)	1 (0.7)	
Road traffic? *n* (%)			
Not at all	80 (53.3)	76 (50.7)	0.64
Slightly	49 (32.7)	54 (36.0)	
Moderately	14 (9.3)	13 (8.7)	
Very or extremely	7 (4.7)	7 (4.7)	
Airplanes and helicopters? *n* (%)			
Not at all	98 (65.3)	97 (64.7)	0.68
Slightly	40 (26.7)	39 (26.0)	
Moderately	11 (7.3)	11 (7.3)	
Very or extremely	1 (0.7)	3 (2.0)	
Other outdoor sources (e.g., construction, music)? *n* (%)			
Not at all	68 (45.4)	79 (52.7)	0.09
Slightly	45 (30.0)	37 (24.6)	
Moderately	22 (14.7)	22 (14.7)	
Very or extremely	15 (10.0)	12 (8.0)	

by approximately one half at the 90-day visit (Table 3). To contextualize participants' sensitivity to noise from the AP, participants were also asked to rate their sensitivity to other sources of noise in the area. The purpose of including these other noise sources was to establish participants' baseline sensitivity to noise. No significant differences between the 30-day and 90-day visits were observed for the questions addressing noise from road traffic, airplanes and helicopters, or other outdoor sources (Table 3). At both follow-up visits, most participants were either not bothered or slightly bothered.

HOBO data from 45 participants verified that the APs were running nearly all the time during the past 30 days of the follow-up visits. At the 30-day visit, the APs were running an average (standard deviation) of 98.9% (3.8%) of the time during the past 30 days, ranging from 76.4 to 100.0%. At the 90-day visit, the APs were running an average of 99.0% (2.8%) of the time, ranging from 83.7 to 100.0%.

Qualitative results

During structured interviews of 26 participants, comments were collected on how much the noise from the APs bothered, disturbed, or annoyed them. Some participants admitted to being surprised by the noise from the units and wished they had been warned about the noise levels beforehand:

> *"The highest level on the air filter was unmanageable. Really loud, could hear it in every room. On the middle setting it was fine. There were some assumptions to put it as high as you can. Even in the bedroom we like white noise, but it was ridiculous."*

In contrast, a few participants reported liking the noise produced by the APs, comparing it to white noise:

> *"They would also help to sleep well with noises so at night it would help me sleep better, the outside loud noise would be drained out."*

Participants were asked about how often they moved the APs, what speed they ran the units at, how often they changed the speed, and how often they turned the APs off. Most participants reported not moving the APs at all during the previous month. The three participants who did move the units reported doing so because they had guests and wanted the AP out of the way, needed to clean around or under the unit, or wanted to access something the unit was blocking:

> *"Small house and big filters-- needed to access the drawer behind the filter; fix air conditioner behind the filter; and do housework, etc."*

Consistent with the results from the questionnaire, participants reported keeping the APs running on speed II (medium) or III (high). More than half of participants interviewed admitted to changing the speed at some point throughout the trial, and about a quarter said they changed the speed daily. Some participants reported changing the speed when they were not home, while others did so when the noise level was too loud, such as while watching television or making phone calls for work:

> *"The filters would be loud sometimes; so, I would need to change the speed to a lower setting to speak on the phone. If you put it at three, it would sound stimulating, but if you put it back to two, it would be ok. I changed the speed of the filter in my living room more than the one in my bedroom."*

Although most interviewed participants reported they did not turn the APs off in the previous month, some participants did turn them off. Noise annoyance and disruption were reported reasons for turning the units off, as was being out of town:

> *"I keep the downstairs filter off half the time because noise is disruptive, I turned it off to watch TV…"*

Additionally, participants reported turning off the APs when the air blowing out felt too cold, especially on cold days:

> *"The cold air was making the room too cold on some very cold days."*

In addition to complaints of noise annoyance and cold air, some participants also felt the units were too large and bulky and took up too much space in the home:

> *"One of the bedrooms is small, so takes up space. The noise bothers my husband, but no one else has complained. The filters push out cold air, which is not good for cold season because it competes with the radiators."*

> *"…[the filter] takes up space that could be used for something else, its crowded in the bedroom, and I have to squeeze past it."*

Many participants were also quite concerned about the energy consumption costs and expressed interest in more affordable options. However, most participants were positive about having APs in their homes and even wanted to keep the units after the trial ended.

Discussion

The purpose of the present study was to report participants' reactions in using portable home APs to reduce TRAP exposure. Results from the questionnaires, HOBO data, and structured interviews all suggest that individuals generally have positive reactions towards using APs for home use. Despite AP noise being mentioned during the structured interviews, most participants were not bothered by it, just as they were not generally bothered by other noises. Participants had very high adherence to AP use, keeping them on nearly every day of the month, for over 23 h a day despite having some concerns about cost of electricity and cold air. Although over half of the participants did change the speed settings, most participants kept the APs on medium speed.

Despite the paucity of published literature about AP acceptability, there are some studies that may serve as points of comparison. One study about the use of APs among 43 residences in China reported that 81.4% of participants did not use the AP at all [19]. Of the 18.6% that used it intermittently, they did so for less than four hours a day, which is insufficient to adequately reduce indoor levels of PM [19]. In contrast, an earlier report by the California Air Resources Board claimed that 57% of AP owners used them continuously every day [20]. Meanwhile, a randomized clinical trial of APs and adherence among low-income children with asthma reported that participants used the APs 80% of the time and adhered to high or turbo settings 60% of the time [10]. In contrast to the aforementioned published studies, the results of our study demonstrate higher adherence to AP use. One previous study of HEPA filtration among cigarette smokers reported similar results to ours, in which participants kept the APs on continuously but adjusted the fan speed throughout the study period [25].

In two European crossover studies to assess AP use and acceptance, participants reported that their main reason to use home APs was thermal comfort, rather than perceived air quality [5, 11]. Participants reported a cooling and freshening effect associated with the APs, which led to increased use in the warmer months and decreased use in the colder months. They admitted to not using the APs for their intended effect of improving air quality, preferring to use them instead as cooling fans. Similar to our findings, responses from their structured interviews noted the presence of a cold draft produced by the APs, which they found bothersome on cold days but refreshing on warmer days.

Our study has several strengths. The data were collected within a rigorous randomized crossover trial of APs, assuring strict adherence to protocols. We also had three different types of data to cross-check responses. Consistency across multiple data sources improves our confidence in our findings. There were, however, also limitations to our study. We did not have each data source from each participant and some outcomes were subjective, such as tolerance to noise. Generalizability of our findings is likely limited to near highway populations in the Northeastern United States.

Conclusion

Our findings suggest that near highway residents can be receptive and adherent to using APs in their homes on a regular basis. The general concerns raised were noise, draft felt due to air movement, space occupied by the units, and electricity use. At least within the context of a research study in which they were asked to keep APs on, most participants were willing to do so for up to a month, twice, albeit on the moderate, rather than high setting. Given the paucity of literature on this issue and the critical role resident behavior will play in success of AP interventions, further research is warranted, including larger sample sizes, different populations, and the relative acceptability of different AP models.

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Authors' contributions

All co-authors read, provided feedback on, and approved the manuscript. KSS took the lead on writing the manuscript and contributed to the analysis. LSM led the qualitative analysis and contributed to writing the manuscript. SLG and GMB contributed to the qualitative analysis. AG managed quantitative data. TVD led the field work as project manager, including recruitment, participant home visits and management, and data collection. NH collected and analyzed HOBO data. AM assisted with data collection and management and helped obtain consents. WZ acted as a community partner and contributed to study design and approach to field work. WGG contributed to recruitment as a community partner. EM contributed to study design, oversaw adherence to clinical trial standards, performed the quantitative analysis, and contributed to writing the manuscript. DB led design of, and directed, the study and contributed to writing the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All health professionals and participants provided written informed consent before participating. Ethics approval was obtained from the UConn Health Institutional Review Board Human Subjects Protection Program (IRB Number: 20-109O-2). Trial Registration: ClinicalTrials.Gov, NCT04279249. Registered 09 October 2019. https://clinicaltrials.gov/show/NCT04279249.

Consent for publication
All study participants were informed and consented to that the outcomes of the study were to be published but that no details would be divulged from which the participant could be identified.

Competing interests
The authors declare that they have no competing interests.

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