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Use of Free-standing Filters in an Asthma Intervention Study

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Abstract

This study characterizes the use of HEPA air filters provided to 89 households participating in an intervention study investigating the respiratory health of children with asthma. Freestanding filters were placed in the child's bedroom and monitored continuously for nearly a year in each household. Filter use was significantly affected by study phase, season and monitoring week. During the “intensive” weeks when a community education worker and a field technician visited the household, the use rate averaged $70 \pm 33\%$. During season-long “non-intensive” periods between seasonal visits, use dropped to $34 \pm 30\%$. Filter use rapidly decreased during the 3 to 4 weeks following each intensive, was slightly higher in spring, summer, and in the evening and at night when the child was likely to be home, although households did not follow consistent diurnal patterns. While participants expressed an understanding of the benefits of filter use and reported good experiences with them, use rates were low, particularly during unobserved non-intensive periods. The provision of freestanding air filters to individuals or households must be considered an active intervention that requires monitoring and evaluation, otherwise unknown and unexpected patterns of filter use may alter and possibly bias results due to exposure misclassification.

Keywords

Air quality; behavior; HEPA; indoor environment; intervention; exposure misclassification

Introduction

Free-standing air filters, also called room air filters or purifiers, can easily and effectively reduce indoor concentrations of PM by 20–80% (Fisk, Faulkner et al. 2002, Batterman, Yu et al. 2005, Eggleston, Butz et al. 2005, Xu, Raja et al. 2010, Butz Am, C. et al. 2011, Du, Batterman et al. 2011), and their use is often recommended to reduce exposure to air pollutants (McDonald, Cook et al. 2002, Sublett, Seltzer et al. 2010, Sublett 2011). We previously evaluated free-standing HEPA (high-efficiency particle arrestor) filters placed in both living rooms and bedrooms of homes in Detroit, MI, many of which contained cigarette smokers. Filters reduced PM levels in nearly all homes, and reductions averaged 69 to 80%

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on days when the filter was used at least 75% of the time (Batterman, Yu et al. 2005, Du, Batterman et al. 2011). Smaller changes, PM₁₀ reductions of 30–39%, were found for HEPA filters installed in homes in Baltimore, MD based on measurements at filter installation, and 6 and 12 months later, as compared to a control group (Eggleston, Butz et al. 2005).

Asthma can be exacerbated by environmental factors such as particulate matter (PM), environmental tobacco smoke (ETS), household dust, and various allergens (NHLBI 2007). The use of filters has been associated with improved respiratory health among children and adults with asthma (e.g., (Myatt, Minegishi et al. 2008, Sulser, Schulz et al. 2009, Xu, Raja et al. 2010, Butz Am, C. et al. 2011), although their environmental and health benefits have not always been reproducible (Warburton, Niven et al. 1994, Wood, Johnson et al. 1998, Reisman 2001, McDonald, Cook et al. 2002). The inconsistency among studies may be attributable to several factors. First, several studies have used a small number of participants or households, e.g., fewer than 15 subjects (Verrall, Muir et al. 1988, Morris, Helm et al. 2006), or short intervention periods, e.g., less than one month (Brehler, Kutting et al. 2003, Morris, Helm et al. 2006, Brauner, Forchhammer et al. 2008). Results from such studies may not be representative, allow sufficient acclimatization, or provide sufficient power to obtain meaningful results. Second, although several studies have measured changes in PM, dust and allergens (VanderHeide, Kauffman et al. 1997, Wood, Johnson et al. 1998, Van der Heide, Van Aalderen et al. 1999, Francis, Fletcher et al. 2003, Sulser, Schulz et al. 2009), PM concentrations and filter effectiveness have been measured only rarely. Third, many factors can affect exposures and filter effectiveness, e.g., the strength and types of indoor emission sources (Sulser, Schulz et al. 2009), outdoor pollutant concentrations (Eggleston, Butz et al. 2005), room and building size (Morgan, Crain et al. 2004), and air exchange rates (AERs) (Wood, Johnson et al. 1998). These factors are rarely known, measured or adequately controlled.

A fourth factor affecting filter performance, and the focus of the present paper, is consideration of comparative filter use. Here, filter use is referred to as the duty cycle, that is, the percentage of time during which the filter is operating. Only four studies have measured filter use in the field (Wood, Johnson et al. 1998, Eggleston, Butz et al. 2005, Sulser, Schulz et al. 2009, Butz Am, C. et al. 2011). While these studies used different methods and criteria, and little information regarding filter use was presented, the literature suggests that filter use can vary widely among study participants, and that the provision of filters in a study should not be considered a passive intervention. Although filters require minimal attention from participants, filter units must be placed appropriately, powered, turned on and left running, and filter elements replaced or maintained at appropriate intervals. Occupants may be disinclined to use filters due to their noise (Sulser, Schulz et al. 2009, Xu, Raja et al. 2010), drafts, perceived temperature changes and electricity cost, especially low-income families (Krieger, Song et al. 2000, O'Toole, Parker et al. 2011). If use is unconfirmed, then exposures in intervention studies may be misclassified, e.g., exposures of individuals in treatment and comparison groups may be similar if filters are not used, thus increasing the likelihood of obtaining negative results.

Objectives

This study characterizes air filter use in an intervention study that examines the efficacy of stand-alone filters to reduce indoor particulate matter (PM) concentrations and improve respiratory health. A total of 89 households, each containing a child with intermittent or persistent asthma, was provided with HEPA air filters, instructions, and recommendations for its use. Filter use was monitored continuously during week-long visits, conducted seasonally and called “intensive” periods when the children's health was evaluated, and during season-long periods between the intensives, called “non-intensive” periods. We

evaluate diurnal, weekly and seasonal patterns, and estimate compliance with study goals and recommendations for filter use. This information is relevant to interpreting results of earlier intervention studies using filters, and for informing actions designed to promote filter use and improve air quality and respiratory health.

Methods and Materials

Study design, recruitment, and schedule

As part of a community-based participatory research (CBPR) project, we studied 126 households in Detroit, Michigan. Most households were low income, and African American or Latino. Households were recruited using a screening questionnaire (Lewis, Robins et al. 2004) distributed in the community, and eligibility criteria included having a child from 6 to 12 years of age identified as having probable asthma or symptoms consistent with asthma, and the availability of a grounded electrical outlet in the child's bedroom. Households were randomly assigned to either a “control” group receiving only community health worker (CHW) home education visits, a “standard” intervention group receiving a free standing room air filter to be placed in the child's bedroom along with the CHW visits, or an “enhanced” intervention group, receiving an AC at the start of the subsequent summer, as well as the filter and the CHW visits. Households entered the study on a rolling basis, and were followed for at least six months (the average enrollment was nine months).

The interventions used a stand-alone HEPA air filter (Whispure 510, Whirlpool Corporation, Benton Harbor, MI) that incorporates a porous prefilter, HEPA second filter, centrifugal fan, upward discharge, and four fan speeds. The manufacturer states a maximum clean air delivery rating of 330 CFM ($9.36 \text{ m}^3 \text{ min}^{-1}$). Additional characteristics and performance of these filters have been described previously (Batterman, Yu et al. 2005, Du, Batterman et al. 2011, Batterman, Du et al. 2012). Most of the residences and bedrooms where the filter was installed were fairly small, e.g., the measured bedroom volume averaged 28 m^3 and ranged from 13 to 110 m^3 (Du, Batterman et al. 2011). The window-type AC unit (FAA062P7A, Frigidaire Augusta, GA) had a maximum cooling rate of $6,000 \text{ BTU hr}^{-1}$ ($620 \text{ cooling W hr}^{-1}$), a thermostat, and three speeds.

The technician and interviewers instructed caregivers on the use of the filter and AC, if installed. To achieve the best performance, participants were instructed to operate the filter continuously at the highest speed tolerable considering noise and comfort, and to close the door of the bedroom where the filter was placed as much as practical. Participants were shown how to clean the pre-filter. Our technician replaced pre-filters and main filters after 6 months of operation. Filters and ACs were provided at no cost, and could be kept by the household after the study concluded. Households received \$10 for the home inspection; \$15 for each week-long data collection home visit; and \$15 for electricity consumed by the filter during each visit. (Households in the control group, which did not receive filters, also received \$100 plus the same incentive for each data collection, visit; these households are not further discussed in this paper.)

The study design, protocols and compensation structure were developed in concert with our community partners. Written informed consent was provided by participating families. All protocols were reviewed and approved by the University of Michigan Institutional Review Board.

Walkthrough and caregiver surveys, and environmental and health monitoring

Week-long “intensive” visits were scheduled and conducted on a seasonal basis at each household for health assessments and environmental measurements, most of which were conducted separately. These included the initial (“baseline”) visit and two or three follow-up

(“seasonal”) visits. Separate from these assessments, during the 2 to 3 month-long “non-intensive” periods between intensive visits, households were visited by a trained community education specialist (CES) who provided education and other supplies focused on environmental control for asthma. CES interactions with families did not involve the air filter until roughly midway through the study when we found that families were turning off filters. Participants received postcards, newsletters, and telephone calls to schedule the next visit and aid participant retention. At the conclusion of the study, a focus group was conducted to identify factors that influenced the household's use of the filters, and a structured telephone interview was administered to caregivers (n=63 participated) for the same purpose.

Exposure assessment activities included walkthrough inspections in each house, caregiver surveys, and indoor air quality measurements during each week-long intensive, which included PM, carbon dioxide, volatile organic compounds, temperature, humidity, air exchange rates, and tracers of environmental tobacco smoke (Du, Batterman et al. 2011, Batterman, Du et al. 2012, Du, Batterman et al. 2012). To monitor filter use, a circuit and data logger was installed inside each filter to record its power consumption, from which fan operation and speed were determined using power thresholds calibrated for each filter unit. (A schematic and instructions are available from the corresponding author.) Filter use was recorded at 5 min intervals during the intensive weeks, and at 1 or 2 hr intervals during non-intensive periods (a lower rate due to memory constraints of the logger).

Data analysis and modeling

Filter use is reported as the percentage of the time the filter is operating over daily, weekly, and seasonal periods. Descriptive statistics and plots showing the cumulative probability of filter use and fan speed were calculated. To obtain study-wide results that weighted households equally, means were calculated for each household. Time of day, and weekday and weekend use data were determined. To examine use patterns, filter speed data was reduced to a binary (on/off) variable. The 5-min data collected during intensives were averaged into 2 hour (block) intervals, and then into daily and weekly averages. Each average required at least 50% valid values; otherwise, it was noted as missing. Weekly filter use after baseline and seasonal intensive visits was plotted. Differences between medians were tested using Mann-Whitney nonparametric tests, and between means using F and Tukey's tests.

Statistical models were used to identify factors affecting filter use during both intensive and non-intensive periods, and to examine changes in use over time. These models used general estimating equation (GEE) models to account for repeated measures, i.e., multiple home visits, as described in the Supplemental Materials.

Results and discussion

Sample population

Field data were collected from March 2009 to September 2010, and the final sample included 126 households randomized to the control group (n=37), the standard intervention group (n=47), and the enhanced intervention group (n=42). This paper reports on the 89 households in the two intervention groups that received filters, and includes 89 baseline visits and 163 follow-up visits. On average ($\pm$ standard deviation), each participant was monitored for 37 ± 14 weeks, and non-intensive periods were 14 ± 4 weeks long. Most (88%) households had two or more intensive weeks with valid use monitoring (n=53 for 3 intensive visits, n=25 for 2 visits, n=8 for only baseline visits; and n=3 for 4 or 5 visits). Filter use by the standard and enhanced groups did not differ (including both use and filter speed; multinomial test, $p=0.37$; Table 1), thus, subsequent analyses combine these two groups. In

addition, these groups did not differ with respect to most environmental measurements, e.g., PM levels, as well as other household characteristics (Du, Batterman et al. 2012).

Patterns and trends of filter use

Filter use varied considerably over time and between households. Use was much higher during the intensive periods when households were visited several times, e.g., use during the baseline week was $84 \pm 27\%$ ($n=74$) and $63 \pm 33\%$ ($n=154$) in subsequent seasonal visits, compared to the non-intensive periods when households were not visited and use dropped to $34 \pm 30\%$ ($n=148$, non-intensive periods 1 and 2; Table 1). A second trend was a decline in use during both intensive (baseline and seasonal visits) and non-intensive periods (Figure 1). Third, use varied dramatically among households during intensive and non-intensive periods, as shown in cumulative distributions of filter use during (Figure 2) and by individual level data (Supplemental Figure 1). Filter use was continuous or near continuous ($>95\%$ use) by 17% ($n=15$) of the households during intensive periods, but by only 3% ($n=2$) of households during non-intensive periods. No use, little or moderate use of filters ($<50\%$ use) was made by 23% ($n=20$) of households during the intensive periods, and by 70% ($n=57$) of households during non-intensive periods. This low compliance with our recommendations for filter use is striking and further discussed below. $\pm$

Filter use during intensive and non-intensive periods was moderately correlated among households, e.g., Spearman correlation coefficients mostly ranged 0.4 to 0.6 (Table 2), but approximately a dozen households did not use filters consistently between these two periods, mostly due to high use during intensives and (very) low use during non-intensive periods. Use during the baseline intensive period, when households first received the filter, was a poor predictor of subsequent use patterns (correlation coefficients from 0 to 0.27; Table 2). Most households somewhat or greatly decreased filter use after an intensive visit; only a few households increased use (Supplemental Figure 3).

Filter units were most frequently set to the highest fan speed, following our recommendations (Table 1; Supplemental Figure 2). The low speed was the next most commonly selected.

In summary, the filter use monitoring revealed several findings. Households displayed great variability in their use of filters, and filter use in one period was not a strong predictor of use in another period. Use during the unobserved non-intensive periods was particularly low, but partially rebounded during the subsequent intensive visit to the household, though. Overall, filter use declined over time.

Weekly and seasonal trends

Following the intensive visits to the households, filter use decreased rapidly over a period of three to four weeks and then leveled off until households were next visited for a health and environmental assessment. Observed trends fit exponential models described in the Supplemental Materials, which showed that the effect of the home visit on use behavior was short-lived. A similar analysis showed that families did not modify filter use during non-intensive periods in anticipation of an upcoming intensive visit by our staff.

The statistical models used in above analyses showed that filter use was an average of 9 to 10% higher in spring and summer seasons as compared to winter (the reference period; Supplemental Table 1). Higher use during the summer might be a result of cooling provided by the filter's fan, although this effect is likely small given the filter's vertical exhaust.

Diurnal trends

Analyses were performed at two levels of aggregation to reveal diurnal trends. The first examined behaviors at the household level. Households that used filters nearly continuously (95% use) or rarely (5% use) were excluded since these households would show negligible diurnal changes. This omitted 20% of households (n=17 of 87 during the intensive periods; n=16 of 81 in the non-intensive periods). The remaining households were grouped into tertiles by the average use across the study period, and the resulting low, medium and high groups had filter use averaging 6–47%, 48–72%, and 73–94%, respectively, during intensive periods, and 6–23%, 24–48% and 49–94% during non-intensive periods. Then, diurnal trends were determined for 2-h blocks for each group. During the midday period when the child was less likely to be at home, use decreased by 5 to 10% for both non-intensive (Figure 3A) and intensive periods (Supplemental Figure 4A). Weekend and weekday periods showed similar patterns (data not shown). This effect was not strong, a result of households having inconsistent patterns of diurnal use.

The second level of aggregation analyzed diurnal patterns at the household-day level, which allowed a household's (tertile) group to change from day to day. (The prior analysis grouped by the household's average use across the study.) As before, days when daily filter use averaged 95% or 5% were removed, which omitted 74% (n=11,228 of 15,089) of daily observations in the non-intensive periods, and 69% (n=873 of 1,267) of observations in the intensive periods. Again, the trimmed data were split into tertiles. For the non-intensive periods, low (6–33% use), medium (34–50% use) and high (51–94% use) groups showed distinct and strong diurnal trends (Figure 3B). The middle tertile showed the greatest diurnal fluctuations, with the highest use (51–79%) at night (10 pm to 6 am), and much lower use (12–29%) during daytime (8 am to 8 pm). In the bottom tertile, use peaked to 40–50% in the evening (10 to 12 pm), and was at a nadir (3–15%) during the day (8 am to 6 pm). A different trend was seen for the high use tertile in evenings (6 pm to 10 pm) during the intensive periods when use dropped from about 80% to 65% (this group had a relatively small sample size; Supplemental Figure 4B). Again, weekend and weekday patterns were similar.

These analyses show that when households changed filter use during the day, which occurred on about a third of study days, use generally increased in the evening and at night when the child was likely to be home. This suggests that some study participants attempted to utilize filters in a manner that they believed would benefit their at-home child. However, in cases where filter use rates were very high, use slightly decreased during the evening. Possibly, this subset of households turned off filters for noise or comfort reasons, perhaps to help their child fall asleep, and then later at night turned them back on. These trends were not consistent across or within households.

Filter use by study participants

In designing and implementing the intervention study, we provided participants with what we felt were simple and straightforward instructions and guidelines for the filters, and we expected high use rates by participants, thus allowing us to evaluate hypotheses related to possible changes in the health outcomes of the children in the study. Filter use rates were evaluated by household using three minimum weekly use criteria (25, 50 and 75% of the time within a week) and three consistency criteria (0%, 33% and 67% across the weeks in the study period). For example, high use might be indicated by a household that makes near continuous (75%) use of the filter on most (67%) weeks in the study. The upper three pie charts in Figure 4 display use rates across households for these criteria during intensive periods; the lower three apply to non-intensive periods. High use rates (75% use on 67% of study weeks) were attained by 49% (n=43) of households during the intensive

periods but only 12% (n=10) during non-intensive periods (Figures 4C and F, respectively). With the use criterion relaxed to 50%, use rates increased to 68% (n=59) during seasonal intensives and 16% (n=13) during non-intensive periods (Figures 4B and D). While calculated use rates depend on the use and consistency criteria, few households maintained high levels of filter use across the study, especially during non-intensive periods.

Comparison to the literature

As noted, four studies were identified that included information regarding participant compliance and/or filter use. In a study of 35 cat-allergic adults, HEPA filter use was monitored continuously during 3-month intervention period. Airborne Fel d1 levels were significantly reduced in the bedrooms of participants who were compliant with the use of an active air cleaner (15 of 18 subjects in the active group, 80% use), and trends toward clinical improvement were found (Wood, Johnson et al. 1998). Another pet allergen study in which filter use was monitored for 12 months found high compliance (30 of 33 patients with 50% use) and lower allergen levels, but no effect on health outcomes (Sulser, Schulz et al. 2009). In a study of inner-city children with asthma, 75% of families (33 of 44) indicated that filters were used all or nearly all of the time, however, use monitoring showed only 48% (n=21) operated the filters at least half of the time (Eggleston, Butz et al. 2005). Lastly, in a 3-arm air cleaner and health coach intervention study of 126 inner-city children with asthma, filter use averaged 59% among the 13 households (of 82 with filters) monitored for 6 months and informed that filter use was being monitored (Butz Am, C. et al. 2011). In the small group monitored, adherence with instructions to use the filters continuously was considered to be moderate.

Nature of filter-based interventions and behavioral inferences

In previous studies, filter interventions have been assumed to be largely passive in nature, requiring essentially no action by study participants, and thus the expectation has been that filters would be operating and that PM levels in the controlled space would be substantially lowered compared to uncontrolled spaces. In present study, in which participants were blinded regarding filter use monitoring, this assumption is shown to be false. Very few participants (6%) maintained high levels of filter use (>90%) during the approximately 1 year-long study. Rather, use varied widely among participants and frequently changed at both weekly and hourly scales. Use rates were much higher during each week-long intensive period when our staff visited for purposes of health monitoring and environmental sampling. However, use dropped greatly during other study periods. Understanding these and other use patterns -- and their underlying determinants -- is essential for interpreting and designing filter intervention studies, and for improving actions aimed at promoting environmental health.

Based on the follow-up interviews and the focus group, all study participants reported positive experiences regarding the air filter, and most appeared to understand the benefits for their child. Some participants (particularly in the no or low use groups) mentioned suggested several barriers for filter use, including perceptions of comfort (drafts), cost, noise, and that they 'forgot' to turn it on. The diurnal trends of filter use, e.g., increased use when the child was at home, tend to support the participants' feedback. Though not directly expressed, participants may have lacked an understanding of the need to run the filter continuously, not just when the child was at home. A few participants indicated that the filter was not kept in the children's bedroom, as recommended, because it was needed elsewhere or that it took up too much space in the bedroom. All participants surveyed said that they understood that the filter could improve asthma, air quality or sleeping, and would recommend filters to other caregivers of asthmatic children. Participants felt that the CESs communicated and interacted well with the participants, and established mutual trust.

Many factors could affect a participant's attitudes and actions, e.g., their child's asthma severity status, expectations regarding the efficacy of their behaviors and the effect of the filter, and socioeconomic and environmental factors. We speculate that observed filter use patterns could be explained by several factors. First, the high use during the initial baseline period may reflect a “novelty” effect when the filter was first introduced to the participants. Second, high use during the baseline period and the rebound in use during subsequent intensive visits may represent a “good behavior” effect, reflecting participants' understanding of how filters should be used, and also a “Hawthorne” effect in that the presence of our staff altered individual behavior. After the intensive visits, 3 to 4 weeks were needed until trends leveled-off, suggesting a degree of retention and sustained action related to the CES's message. Third, the time-of-day analyses suggest “economic” concerns among a subset of participants, i.e., filters were used primarily (or only) when their child was home, a way to reduce energy costs but still be efficacious. This suggests that participants had an understanding of the potential benefits of the filters, and/or a belief that filters would be as effective if only used when the child was home. This low-income population is very sensitive to cost, and while households were reimbursed for the increased cost of electricity consumption attributable to the filter, they likely recognized that they would save money by not using the filter. The low and intermittent use of filters also may reflect participants' views of asthma as an episodic (and not chronic) health problem, resulting in a tendency to address it episodically. Finally, the drop-off in use late in the study, especially during the third non-intensive period, suggests participant “fatigue.”

The increased filter use in spring and summer suggest that thermal comfort is a concern that discourages filter use, and that in some cases, filters might be used for cooling purposes. Finally, this and another study (Eggleston, Butz et al. 2005) suggest that while participants are inclined to report good experiences with filters or high compliance rates, these may not be confirmed by objective measurements.

Enhancing filter use and improving intervention studies

In this first report of filter use patterns in a community-based participatory research (CBPR) intervention study, filter use varied widely. In most cases, filter use was not maintained, and use rates were low. It could be inferred that participants appeared to discount the potential benefits of the filter. The barriers to filter use, identified above, may also apply to other measures aimed at improving the indoor environment, e.g., use of specific cleaning equipment and practices, and integrated pest management.

Five suggestions are made to improve compliance and attain longer lasting improvements in both community and research settings. First, more frequent and more explicit attention to filter use during interactions with participants would increase awareness and encourage filter use as well as adherence with study recommendations. Second, “unblinding” the monitoring of filter use, and possibly enhancing awareness of filter use, e.g., using a display of the time the filter has been used on the device itself or reporting back to participants, might encourage behaviors to use filter. For manufacturers, costs of adding timers to free-standing filters that count and display the number of hours or fraction of time the filter is on, possibly linked to a positive message, would be minimal. Third, the use of more “passive” interventions might be advantageous. For PM removal, this may include use of enhanced furnace filters, rather than free-standing filters used in the present study. However, furnace filters also require maintenance, can be circumvented (e.g., removed), can only be used in residences with forced-air systems, are only effective during the heating and cooling seasons (if central air conditioning is present and used), and can promote room-to-room migration of pollutants like ETS. Fourth, an objective evaluation of use, e.g., measurements of filter use rates or PM concentrations, is necessary to understand the potential for exposure misclassification in epidemiological studies, and possibly to adjust (as weights or covariates)

statistical models. Self-reported use measurements are not recommended. Fifth, air filter studies should not assume a passive nature of air filter use, but rather should include more intensive behavioral change strategies that consider the understanding of and barriers to air filter use among participants (Glanz, Rimer et al. 2008).

Study limitations

Limited information pertaining to factors that may affect filter use, such as expectations and concerns of participants, was obtained prior to the intervention. Feedback on reasons for noncompliance was not obtained until the study was completed. Due to these and sample size limitations, the statistical models could not investigate possible interactions among season, filter use, air conditioning and smoking. The relationship between personal, demographic and household factors, e.g., income, education, number of household residents, and filter use was not investigated; this will be addressed in a subsequent paper.

Conclusions

This paper investigated the use of free-standing filters in an intervention study of 89 households of children with asthma. Filter use averaged $70\pm33\%$ during week-long intensives when the household was visited by a community education worker and technician for health and environmental measurements, but dropped to only $34\pm30\%$ during the multi-month periods between intensives. Filter use decreased rapidly over the 3 to 4 weeks following each intensive, was slightly higher in spring and summer, and often increased in the evening and afternoon when the child was likely to be home. While participants expressed an understanding of the benefits of filter use and reported good experiences with them, use rates for reasonable use and consistency criteria were low, particularly during non-intensive periods. In an epidemiological study, air filters must be considered an active intervention that requires evaluation and monitoring, otherwise unknown and unexpected use patterns may alter and possibly bias study results due to exposure misclassification. The information and methods presented in this paper can help to interpret results of previous studies using filters and other interventions, and can inform health literacy and other programs designed to promote the use of filters and other actions aimed at improving air quality and health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Highlights

- Epidemiological studies are inconsistent regarding the effectiveness of filters.
- Filter use was unexpectedly low use among study participants.
- Provision of free standing filters should be considered an active intervention.
- Enhanced awareness of filter performance might encourage behaviors to use filters.
- Filter use should be monitored to reduce exposure misclassification.

Figure 1.

Filter use over study, showing week-long baseline and seasonal intensive visits 1 and 2, and non-intensive periods 1 to 3. Number of households-weeks (n) and number of households shown as n/N. Plots show median, interquartile range, and 10th and 90th percentile.

Figure 2. Cumulative probability of weekly filter use for intensive and non-intensive periods based on household-weeks.

Figure 3.

Filter use by the hour of day for non-intensive periods. A: Use by household-study grouped by tertiles of average use among households with low (6–23%), medium (24–48%) and high (49–94%) use groups after excluding households with little use (5%, n=13) or near continuous use (95%, n=3). B. Use by household-day grouped by tertiles of average daily use with low (6–33%), medium (34–50%) and high (51–94%) use groups after excluding household-days with little use (5%, n=7,685) or near continuous use (95%, n=3,543).

Figure 4.

Fraction of study households complying with various weekly filter use (average within the week) and consistency criteria (minimum use in each week of the study) for intensive and non-intensive periods.

Table 1

Filter use and fan speed by intervention group for intensive and non-intensive periods.

Filter Use Speed	Intensive Visits			Non-intensive Periods		
	Standard	Enhanced	All	Standard	Enhanced	All
N*	126	102	228	83	65	148
Low	12.5 (21.5)	12.9 (21.9)	12.7 (21.6)	7.4 (10.6)	8.7 (13.1)	8.0 (11.7)
Medium	4.7 (14.3)	4.0 (10)	4.4 (12.5)	2.6 (5.5)	3.7 (6.2)	3.1 (5.8)
High	13.4 (23.1)	4.2 (11.3)	9.3 (19.3)	6.0 (11.7)	3.1 (4.8)	4.7 (9.4)
Turbo	44.2 (36.5)	42.2 (35.8)	43.3 (36.2)	19.6 (21.9)	16.4 (21.8)	18.2 (21.8)
On	74.8 (30.1)	63.3 (34.3)	69.7 (32.5)	35.5 (29.8)	32.0 (29.8)	34.0 (29.7)

Standard deviation given in parentheses.

* N is for intensive weeks or non-intensive periods.

Table 2

Spearman rank correlation coefficients for weekly filter use by study period.

Intensive/non-intensive Periods	Baseline	Seasonal Visit 1	Seasonal Visit 2	Seasonal Visit 3	Non-intensive 1	Non-intensive 2	Non-intensive 3
Baseline	1	-	-	-	-	-	-
Seasonal Visit 1	0.186	1	-	-	-	-	-
Seasonal Visit 2	-0.006	0.497	1	-	-	-	-
Seasonal Visit 3	-0.800	0.429	0.607	1	-	-	-
Non-intensive 1	0.266	0.456	0.361	0.500	1	-	-
Non-intensive 2	0.198	0.361	0.517	0.257	0.580	1	-
Non-intensive 3	-0.800	0.657	0.786	0.464	0.900	0.943	1

Bolded values are significant at $\alpha = 0.05$.