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# Allergen levels in inner city homes: baseline concentrations and evaluation of intervention effectiveness

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Allergens in house dust are risk factors for asthma causation and exacerbation, and asthma interventions often focus on exposure reduction using methods that may not be sustainable over time in low-income communities. A randomized controlled trial with up to six home visits was used to evaluate the effectiveness of two interventions focused on reducing dust loading and allergen concentrations in 47 low-income inner-city households in Minneapolis, MN. The interventions, which included education and relatively inexpensive cleaning procedures, were developed using a community-based participatory consultation process with focus groups held in English, Somali, and Spanish to incorporate community feedback from participants into protocols and study design decisions. Change in levels of cat, cockroach, dust mite, and culturable fungi as well as overall dust loading were evaluated by measuring the difference in concentrations before and after the cleaning intervention, and mixed models were used to assess the effect of education and cleaning on baseline allergen levels during the final three home visits. The cleaning intervention significantly lowered dust loading in all households and culturable fungi levels in single family homes, reduced cat allergen concentrations in homes with cats, but had no significant effect on cockroach allergen levels. The cleaning intervention also modestly decreased the frequency of observed allergen concentrations above suggested health benchmarks for cat, cockroach, and fungi. The cleaning and education interventions had similar effects on baseline allergen levels measured during subsequent home visits; both interventions significantly reduced baseline levels of cat and fungal allergens observed in pre-cleaning samples, but had no significant effect on cockroach allergen levels. Overall, the cleaning intervention modestly reduced potential exposure to risk factors associated with asthma mortality and morbidity in a way that can be implemented by most homeowners or renters, independent of education, income, or the ability to speak English.
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## Introduction

Asthma is one of most common chronic diseases in the United States, and asthma rates are increasing nationwide, especially in children. The importance of the indoor environment for children's health is well-recognized: allergic sensitization and asthma are disproportionately high among inner-city children and increased exposures to indoor contaminants have been proposed as an explanation (NRC, 2000; HUD, 2001; IOM, 2004). House dust, tobacco smoke, and multiple allergens (principally dust mite, cockroach, cat/dog dander, and molds) have been tied to the causation or exacerbation of asthma and related respiratory symptoms (NRC, 2000; Elliott et al., 2007; Wu and Takaro, 2007). Furthermore, evidence suggests that lower income inner-city residences are more likely to have higher concentrations of and children sensitized to cockroach allergens, while higher income residences are more likely to have higher concentrations of and children sensitized to pet and dust mite allergens (Rosenstreich et al., 1997; Leaderer et al., 2002).

Studies have demonstrated that reductions in domestic allergens and asthma rates can be achieved if individuals modify their behavior to reduce exposure to risk factors as well as change their cleaning, pest control, and maintenance practices (Carter et al., 2001; Morgan et al., 2004; Chan-Yeung et al., 2005; Wu and Takaro, 2007). Some interventions have used time-consuming and relatively expensive techniques, such as steam cleaning, to demonstrate statistically significant reductions in dust mite allergen levels (Vojta et al., 2001). Many studies, however, have not investigated the suite of allergens typically present in households, or the cost and effort involved in implementation, and many studies have expressed concerns about sustainability over time (Wu and Takaro, 2007). Given the multiple risk factors and

1. Abbreviations: Bla g1, *Blatella germanica* protein 1; CFU, colony-forming unit; CV, coefficient of variation (%); Der f1, *Dermatophagoides farinae* protein 1; Der p1, *Dermatophagoides pteronyssinus* protein 1; ELISA, enzyme-linked immunosorbent assay; Fel d1, *Felis domesticus* protein 1; GM, geometric mean; HARS, Home Allergen Reduction Study; NCICAS, National Cooperative Inner City Asthma Study; SHIELD, Schools Health Initiative: Environment Learning and Disease Study

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increasing burden that asthma places on families and communities, it is important to test the efficacy of intervention strategies that affect the suite of common risk factors and can be implemented by a diverse population of residents, including those from low-income and/or non-English-speaking communities that bear the largest burden of this chronic disease (Takaro et al., 2004; Krieger et al., 2005; Levy et al., 2006).

The goal of this analysis is to assess the feasibility and effectiveness of a home-cleaning intervention designed in consultation with community members to increase the likelihood that it would be implemented and sustained without further outside inputs. To evaluate feasibility, we conducted focus groups with the three main ethnic/language groups (English, Spanish, and Somali) to assess willingness to adapt a version of several techniques that are commonly promoted as interventions strategies. To evaluate effectiveness, a randomized trial was used to assess the change in dust and allergen levels within study households following education and cleaning interventions.

## Methods

*Recruiting*

This study was designed as a random convenience sample of residences that enrolled in a previous population-based random sample (the SHIELD study (Schools Health Initiative: Environment, Learning, and Disease)) (Sexton et al., 2000). As a priority, this study enrolled families who participated in the SHIELD study who still lived at the same address. Recruiting beyond this initial target population involved a progressive tiered approach to reach the desired recruitment goal of 60 families by targeting: (1) new residents of previous SHIELD household addresses, (2) SHIELD families who moved within the South Minneapolis area, and (3) non-SHIELD residents of the Lyndale, Whittier, and adjacent neighborhoods in South Minneapolis. Recruiting occurred between April 2004 and July 2004, with six more families added in December 2004. SHIELD households were recruited by mailing an informational brochure and recruitment letter that included an opt-out card and a postage-paid return envelope. If no active refusal was obtained, follow-up with phone contact and/or door knocking was conducted when feasible. Once all recruiting attempts for SHIELD households were exhausted, a canvassing effort was initiated using multilingual (English, Somali, and Spanish) recruiting flyers in target neighborhoods. Trained bilingual recruiters made all contacts either in person or by telephone. Once contact was made with a potential participant, eligibility criteria for consenting participants were that they must be (1) the head of household and between the ages of 18 and 65; (2) willing to be in the study for 1 year; and (3) have a child present in the home. Informed consent was obtained in person before the start of the study. This study was approved by the University of Minnesota Research Subjects' Protection Program Institutional Review Board, Human Subjects Committee.

*Study design*

A schematic representation of the study design is shown in Figure 1. This was a longitudinal study designed to (1) evaluate the variability in allergen levels over time (Cho et al., 2007), and (2) quantify the individual and joint effects of the education-only and cleaning-only interventions on household allergen levels. As shown in Figure 1, each residence in the study was visited up to six times over a year, and all homes eventually received both the education and cleaning interventions on a randomized basis. To evaluate the effectiveness of the cleaning protocol, dust samples were collected before (pre-) and after (post-) the cleaning intervention, which occurred during household visits 4–6. After completion of the first three home sampling visits, households were randomly assigned to three different intervention groups: arm 1, arm 2, or arm 3. In arm 1, the cleaning intervention was carried out at visits 4 and 6, with an education intervention at visit 5. In arm 2, the education intervention was completed at visit 4, and cleaning interventions at visits 5 and 6. In arm 3, the education intervention was carried out at visits 4 and 5, with a cleaning intervention at visit 6.

The education and cleaning interventions were developed with input from the study population using a community-based participatory model, because community participation has been identified as a key element in effective and ethically conducted research on health hazards (Israel et al., 1998; Swartz et al., 2004; NRC/IOM, 2005). The proposed interventions presented to the focus groups were based on existing best practices suggested by literature review, current practice by public health agencies, and professional judgment. The cleaning and educational intervention was reviewed and revised based on feedback from study participants during focus groups. Focus groups were conducted by recruiting 5–8 study participants from each language group (English, Spanish, or Somali) to discuss asthma risk factors and their willingness to conduct specific cleaning procedures. Focus groups were led by study interviewers who had been trained in focus group techniques, and participants were a convenience sample of those willing to participate from each language group. Focus group discussions were held in the participants' native languages using a fixed question script that asked them to evaluate the study design and proposed interventions. The question path was designed to elicit input and obtain group level responses to questions about education and cleaning methods, and asked the participants to evaluate (1) the educational materials for clarity, and (2) the cleaning methods for feasibility and give estimates of additional time and expense they were willing to expend on an ongoing basis to reduce allergen exposures. Averaged across language groups,

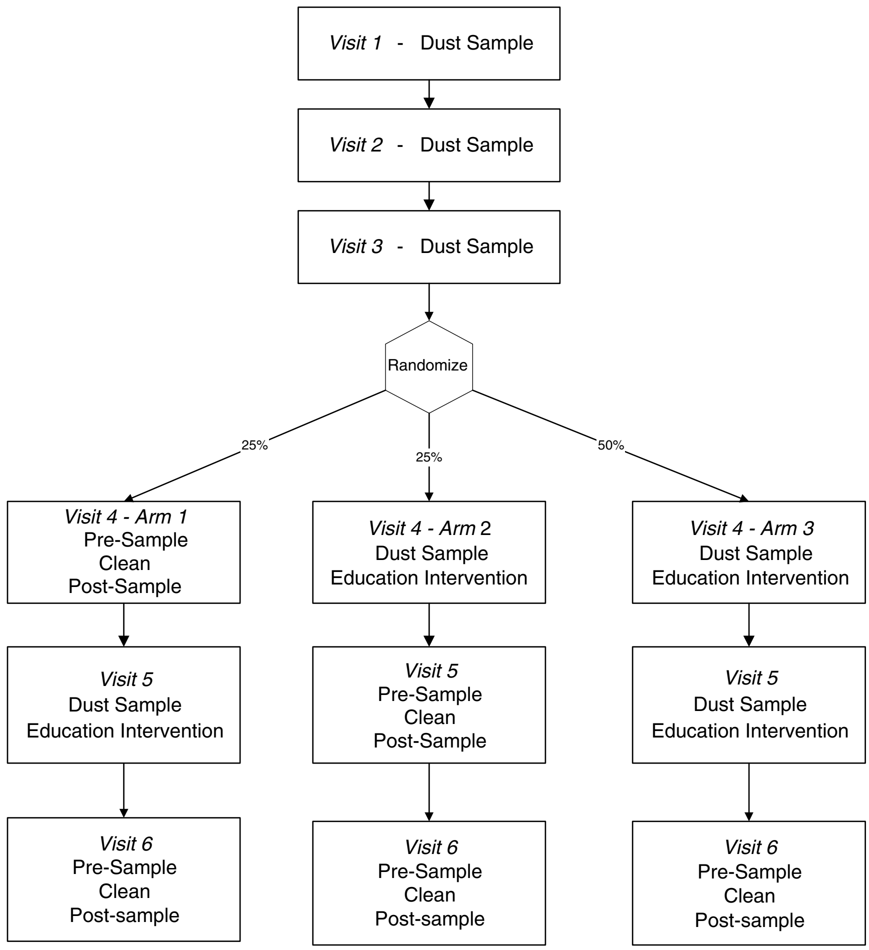


**Figure 1.** Schematic representation of study design for home visits during the Home Allergen Reduction Study (HARS).

responses for additional time spent cleaning was 1–2 h a week, and additional cost participants were willing to incur was <$100.

The education intervention was the provision of fact sheets on cat, cockroach, dust mite, and molds to homeowners during home visits, followed by discussion of content and key allergen cleaning techniques with study staff. Education visits varied in length, with median duration of less than or equal to 15 min. The cleaning intervention used a multi-step process to clean the floors and upholstered furniture in the sample rooms (sample bedroom, kitchen, dining room, and living room) and took a crew of 2–3 study staff less than an hour to complete in most study residences. Carpet, large rugs, and upholstered furniture were vacuumed using a consumer brand vacuum (Hoover WindTunnel model U5453-900) equipped with a Hoover Y-type HEPA bag. The vacuuming protocol called for over-lapping and criss-cross angles to insure thoroughness and consistency, and vacuuming durations were standardized to achieve equivalent times per unit area of surface cleaned. Small rugs that could not be vacuumed were taken outside and shaken vigorously, and bedding was also vacuumed. Hard surface floors were first dry-mopped and then wet-mopped using the Swiffer® brand cleaning wipes. Moistened (wet) wipes contained water, propylene glycol *n*-propyl ether or propylene glycol *n*-butyl ether, and isopropyl alcohol (1–4%). The vacuum cleaner and its attachments, sampling grids, and the bottom of the sampling pump were thoroughly cleaned between home visits.

### *Data collection*

Dust samples for allergens and fungi were collected six times from study homes from June 2004 to July 2005 (Figure 1). To insure the same rooms and locations are sampled in subsequent visits, maps were drawn of the general household with more detail given to the rooms where samples were taken indicating the exact sample locations. Because a minimal amount of dust was needed for lab analysis, each sample cassette had a descending priority to guide for selecting the sample location, with lower priority locations sampled only if the mass available in higher priority location was small. Fungi samples were collected from the living room carpeted floor or upholstered furniture. Dust mite allergen samples were collected from the bedroom floors, living room floors, or upholstered furniture; additional bed-only samples were collected during visits 4–6 in cleaning intervention homes. Cat and cockroach allergen samples were collected primarily from kitchen and dining room floor, with some limited additional sampling from adjacent sections on the living room floors and/or upholstered furniture if dust mass collected was low.

Dust samples were collected using a micro-vacuum sampler (Gilian AirCon 520AC Air Sampling Pump, Gilian Instrument Corp., Wayne, NJ, USA) that has a sampling flow rate of 17 l/min. The dust was collected on 0.8 $\mu$m pore size polycarbonate filters (Model 738 PC, Zefon Analytical Accessories, St. Petersburg, FL, USA) in 37 mm filter cassettes. The samplers were calibrated against a precision rotameter (Gilian Bubble Generator model 800285, Gilian Instrument Corp., Wayne, NJ, USA) to verify flows.

A minimum of three nonadjacent square feet were selected for dust sampling. Each square foot was vacuumed using a template sampled at least four times: vertically, horizontally, kitty corner to kitty corner, and with a circular motion. Dust collection continued until the total dust mass collected was at least 100 mg. Coarse material, such as sand and hair, were avoided, and cassettes were stored at $\sim$40°F for 1–3 weeks before shipping to the analysis laboratory. At the time of sampling, temperature and relative humidity were measured 5 cm above the surface of two rooms, the sample bedroom floor and the living room floor, using either a QTRAK (TSI, Shoreview, MN, USA) or a wet-bulb sling psychrometer.

### *Laboratory analyses*

Dust samples sent to P&K Laboratory Inc. (Cherry Hill, NJ, USA) were sieved to less than 355 $\mu$m and divided into 100-mg dust aliquots, which were then extracted in borate-buffered saline and clarified by centrifugation. Supernatants for allergen analyses were decanted and stored at $-30$°C. Concentrations of the allergens *Blatella germanica* protein 1 (Bla g1), *Dermatophagoides farinae* protein 1 (Der f1), *Dermatophagoides pteronyssinus* protein 1 (Der p1), and *Felis domesticus* protein 1 (Fel d1) were measured separately with monoclonal-antibody-based enzyme-linked immunosorbent assays (ELISAs) (Chapman et al., 1987; Wood et al., 1988). Fungal samples were plated on malt extract agar and incubated at 25°C and then culturable fungal colonies were counted and identified after 7–10 days. The results were reported in micrograms of allergen per gram of dust for Der p1, Der f1, and Fel d1, in units (U) per gram for Bla g1, and in colony-forming units (CFUs) per gram for culturable fungi.

Reference dust samples obtained from a reference laboratory (DACI, Johns Hopkins University, Baltimore, MD, USA) were used for quality control of laboratory performance of ELISA analyses and consisted of two dust batches. Batch I contained high levels of Der f1 (3.46 $\mu$g/g), Der p1 (46.7 $\mu$g/g), and Fel d1 (1,700 $\mu$g/g) and low levels of Bla g1 ($<$0.4 U/g). Batch II contained high levels of Bla g1 (22.8 U/g) and low levels of Der f1 (0.46 $\mu$g/g), Der p1 (0.17 $\mu$g/g), and Fel d1 (45.9 $\mu$g/g). A total of 40 reference dust samples, 20 from each batch, were analyzed over a 1-year period of study. The arithmetic mean (coefficient of variation (CV), % recovery) of Der f1 in batch I was 3.88 $\mu$g/g (27%, 112%), and the majority of the analytical results were within $\pm$1 SD of the reference mean. The mean (% CV, % recovery) of Der p1 in batch I was 26.04 $\mu$g/g (23%, 56%), and the results were consistent between $-1$ SD and $-2$ SD of the reference mean. For Bla g1, the mean (% CV, % recovery) of measured levels from batch II was 10.88 U/g (47%, 48%), and the analytical results were within $-1$ SD of the reference mean. For Fel d1, the means (CVs, % recoveries) of measured levels from two batches (I and II) were 1,715 $\mu$g/g (37%, 101%) and 44.28 $\mu$g/g (47%, 96%), respectively. In general, laboratory performance fluctuated within $\pm$2 SD of the reference means, but there was a consistent underestimation of dust mite and cockroach allergen levels relative to reference concentrations during the study.

### *Statistical Analysis and Related Considerations*

Statistical modeling was motivated by the study design and was performed using SAS (Cary, NC, USA; Version 9.1). Analyses were performed on log-transformed values to normalize the distributions and to equalize variances, and transformed means were exponentiated to obtain geometric means. Concentrations below the laboratory method detection limit (MDL) for that batch were included in the analyses as 1/2 the MDL. Pre- and post-intervention geometric means (GMs) and within- and between-home variances were calculated for each sample type, and *t*-tests were used to evaluate mean differences. Evaluation of the effect of prior education and cleaning in homes used mixed models (PROC MIXED) to control for the effect of repeated measurements and season.

## Results

A total of 59 families were enrolled in the study and the number of completed sampling visits were 53, 48, 50, 49, 48, and 42 for visits 1–6 conducted over a year (Figure 1). At the conclusion of the study, there were 47 households that had completed at least four home visits, and this was the population basis for further analysis. The socio-demographics of the study population are shown in Table 1. Overall, the study population was primarily recent immigrants who lived in rental housing: of the 47 households in the study, 21 resided in single family homes and 26 resided in apartments. The recruited households were predominantly non-white, a majority spoke Spanish or Somali as their first language, and ∼60% had less than a high school education. Eighty-five percent of study households had one or more children, 40% reported a household income of <\$20,000 per year, and ∼40% of the households reported having a child or adult resident who had been diagnosed with asthma at some time in their lives.

The overall distribution of cat, cockroach, dust mite, and fungal levels from pre-intervention samples in carpets, rugs, and upholstery obtained from 47 households are shown in Table 2. The nine residences that had cats had uniformly high cat allergen levels, which were two orders of magnitude larger than in non-cat residences. Notably, homes without cats still had detectable levels of cat allergen approximately half the time. Cockroach allergens were present in nearly 30% of the samples, but were measurable in almost half of study homes sometime during the year of monitoring. The percentage of detectable dust mite samples was low, with Der f1 more frequently detected than Der p1. Cultured fungi levels were measurable in all samples.

**Table 1.** Household characteristics of the study population ($N=47$).

| | Number (%) |
|---|---|
| *Race/ethnicity* | |
| Somali | 13 (27.6) |
| Hispanic | 15 (31.9) |
| White | 10 (21.3) |
| Other[a] | 9 (19.2) |
| *Language* | |
| English-speaking | 19 (40.4) |
| Somali-speaking | 13 (27.7) |
| Spanish-speaking | 15 (31.9) |
| *Family income*[b] | |
| <\$20,000 | 19 (40.4) |
| ⩾\$20,000 | 24 (51.1) |
| *Housing type* | |
| Single family | 21 (44.7) |
| Apartment | 26 (55.3) |
| *Presence of a cat* | |
| Yes | 9 (19.1) |
| No | 38 (80.9) |

[a]American Indian, Asian, African American, or mixed race.
[b]Four households refused.

Overall, 93% (139/150) of the potential intervention visits were successfully completed. The cleaning intervention was conducted at least once in 46 households, and there were 13 pre- and post-intervention sample pairs in visit 4, 11 in visit 5, and 42 in visit 6. As shown in Figure 1, all residences received the intervention at least one time, and ∼50% were randomized to receive the intervention two times. For homes with more than one intervention visit, there was a minimum of 6 weeks and a maximum of 4 months between any two cleaning intervention visits. The intervention process significantly ($P<0.01$) reduced geometric mean dust loading (g/m$^2$) by 49%, and the percent reduction did not vary substantially between home type or surface sampled (Table 3).

In residences with a cat, the cleaning intervention decreased geometric mean cat allergen levels by 43% (Table 4a). This difference was not statistically significant; however, and in ∼10% of study homes, the post-sample was greater than pre-sample. Overall, the reduction was substantial in cat homes, but post-cleaning GM levels (37.3 $\mu$g/g) were still more than 2 orders of magnitude greater than concentration in non-cat households. In residences without cats, post-intervention levels increased slightly, and the increase was not significant by surface, but was when all surfaces were combined.

**Table 2.** Distribution of baseline concentrations during the first four home visits for cat, cockroach, dust mite, and fungi samples measured as concentration per gram dust and per unit area.

| | | | | Per g dust | | Per m$^2$ | |
|---|---|---|---|---|---|---|---|
| Allergen | | $N$[a] | % > DL | GM | GSD | GM | GSD |
| Cat Fel d1 ($\mu$g) | No cat in home | 141 | 63.83 | 0.62 | 4.59 | 0.24 | 7.10 |
| | Cat in home | 36 | 100.0 | 159.7 | 4.54 | 44.71 | 7.05 |
| Cockroach Bla g1 (U) | | 177 | 33.33 | 1.85 | 4.68 | 0.61 | 6.77 |
| Dust mite Der f1 ($\mu$g) | Floor | 136 | 22.79 | 0.43 | 2.59 | 0.18 | 3.67 |
| | Bed | 58 | 34.48 | 0.95 | 3.63 | 0.05 | 5.70 |
| | Bed/floor | 24 | 16.67 | 0.48 | 1.98 | 0.10 | 3.03 |
| Dust mite Der p1 ($\mu$g) | Floor | 136 | 5.15 | 0.31 | 1.62 | 0.13 | 3.06 |
| | Bed | 58 | 10.34 | 0.54 | 2.51 | 0.03 | 2.79 |
| | Bed/floor | 24 | 8.33 | 0.42 | 1.79 | 0.09 | 2.35 |
| Fungus (CFU) | | 177 | 100 | 130,650 | 4.04 | 59,330 | 5.37 |

[a]Samples collected from 47 households with at least four home visits, showing data from visits 1–3 and pre-cleaning samples in visit 4.
Abbreviations: GM, geometric mean; GSD, geometric standard deviation.

**Table 3.** Descriptive statistics of pre- and post-cleaning dust loading (g/m$^2$).

| | | *N* | Pre-cleaning GM | Post-cleaning GM | Distribution of post-cleaning concentration/pre-cleaning concentration among all paired samples Q10 | Q25 | Q50 | Q75 | Q90 | Paired *t*-test Pr > \|*t*\| |
|---|---|---|---|---|---|---|---|---|---|---|
| Total | | 232 | 0.17 | 0.10 | 0.21 | 0.33 | 0.51 | 0.88 | 1.50 | < .0001 |
| Home type | House | 107 | 0.19 | 0.11 | 0.21 | 0.33 | 0.51 | 1.00 | 1.72 | < .0001 |
| | Apt. | 125 | 0.16 | 0.08 | 0.22 | 0.32 | 0.51 | 0.84 | 1.28 | < .0001 |
| Sample surface | Rug/carpet | 124 | 0.29 | 0.17 | 0.22 | 0.36 | 0.56 | 0.91 | 1.64 | < .0001 |
| | Bed | 40 | 0.02 | 0.01 | 0.22 | 0.31 | 0.50 | 0.94 | 3.00 | 0.0014 |
| | Other/multiple | 68 | 0.21 | 0.10 | 0.20 | 0.30 | 0.48 | 0.84 | 1.25 | < .0001 |

Abbreviations: GM, geometric mean; Q, percentile.

Although the intervention reduced dust levels substantially, there was no significant change in geometric mean dust mite concentrations post-intervention, most likely due to the low percentage of detectable samples (Table 2). The intervention had variable effects on cockroach allergen levels, with an overall small but nonsignificant decrease (2%) in concentration for this allergen (Table 4b). This post-intervention decrease was primarily seen in single family homes, which had lower baseline cockroach allergen concentrations compared to apartments. Cockroach allergen levels went up more in rugs/carpets compared to other surfaces, indicating that this surface is harder to clean than others sampled in this study.

As with cockroach levels, fungal spore concentration varied more within than between homes. The intervention reduced overall fungal levels by 25%, but this reduction was not significantly different from baseline (Table 4c). The change in fungal counts did vary by type of housing, with overall fungal levels significantly reduced in single family homes but not in apartments, which had lower baseline levels compared to single family homes. The type of surface sampled did not have a substantial effect on the reduction in GM fungal levels.

Mixed models that controlled for the effect of repeat measures and season were used to explore the effect of prior cleaning, education, and the combined effects of these two factors on allergen levels during the intervention phase of the study. Specific allergen levels at specific points in time were grouped into one of three possible treatment groups (1 = prior cleaning (e.g., arm 1, visit 5), 2 = prior education (e.g., arm 2, visit 5), or 3 = prior cleaning and education (e.g., arm 1, visit 6)) and compared to allergen levels in households without prior intervention (Figure 1). As shown in Table 5, cleaning, education, and the combined effects of cleaning and education significantly reduced the levels of cat allergen compared to homes without prior intervention. Both prior cleaning and prior education had a significant effect on fungal levels when compared to homes without prior intervention, although the joint effect of the two factors was not significant. In contrast, there was no significant difference between the effect of these three factors on cockroach allergen levels compared to nonintervention households, although the effect of prior education approached statistical significance ($P = 0.097$).

## Discussion

This study demonstrates that an allergen-reduction intervention designed with community input and centered on mopping hard surfaces and vacuuming carpets, rugs, beds, upholstery, and hard surfaces significantly reduced overall house dust loading and fungal levels in single family homes, but had less clearly beneficial effects on reduction of other

**Table 4a.** Descriptive statistics of pre- and post-cleaning cat allergen concentrations (μg/g dust).

| | | | | | Distribution of post-cleaning concentration/pre-cleaning concentration among all paired samples | | | | | Paired *t*-test | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | Sampled | Surface | *N* | Pre-cleaning GM | Post-cleaning GM | Q10 | Q25 | Q50 | Q75 | Q90 | Pr > \|*t*\| |
| | Total | | 13 | 89.6 | 37.3 | 0.17 | 0.29 | 0.57 | 0.79 | 1.40 | 0.19 |
| With cat | | Rug/carpet | 2 | 37.4 | 33.4 | 0.57 | 0.57 | 0.99 | 1.40 | 1.40 | 0.85 |
| With cat | | Multiple[a] | 11 | 105.0 | 38.1 | 0.17 | 0.24 | 0.55 | 0.79 | 1.11 | 0.20 |
| | Total | | 50 | 0.17 | 0.23 | 0.55 | 0.74 | 1.00 | 2.33 | 4.80 | 0.028 |
| No cat | | Rug/carpet | 20 | 0.16 | 0.21 | 0.55 | 0.96 | 1.00 | 1.93 | 3.49 | 0.11 |
| No cat | | Multiple | 30 | 0.17 | 0.25 | 0.49 | 0.70 | 0.90 | 2.53 | 12.65 | 0.096 |

Abbreviations: GM, geometric mean; Q, percentile.
[a]Rugs, carpets, smooth surfaces, and bedding.

**Table 4b.** Descriptive statistics of pre- and post-cleaning cockroach allergen concentrations (U/g dust).

| | | | | | Distribution of post-cleaning concentration/pre-cleaning concentration among all paired samples | | | | | Paired *t*-test |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *N* | Pre-cleaning GM | Post-cleaning GM | Q10 | Q25 | Q50 | Q75 | Q90 | Pr > \|*t*\| |
| Total | | 62 | 1.61 | 1.68 | 0.44 | 0.71 | 0.98 | 1.28 | 3.23 | 0.74 |
| Home type | House | 30 | 1.39 | 1.17 | 0.43 | 0.69 | 0.93 | 1.00 | 1.32 | 0.096 |
| | Apt. | 32 | 1.85 | 2.35 | 0.51 | 0.74 | 1.00 | 1.71 | 5.00 | 0.27 |
| Sample surface | Rug/carpet | 22 | 1.77 | 2.05 | 0.44 | 0.56 | 1.03 | 2.00 | 4.48 | 0.48 |
| | Other/multiple | 40 | 1.53 | 1.51 | 0.47 | 0.72 | 0.91 | 1.00 | 1.36 | 0.91 |

Abbreviations: GM, geometric mean; Q, percentile.

**Table 4c.** Descriptive statistics of pre- and post-cleaning fungus concentrations (CFU/g dust).

| | | $N$ | Pre-cleaning GM | Post-cleaning GM | Distribution of post-cleaning concentration/pre-cleaning concentration among all paired samples | | | | | Paired $t$-test |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Q10 | Q25 | Q50 | Q75 | Q90 | Pr > \|t\| |
| Total | | 66 | 99,510 | 76,420 | 0.10 | 0.20 | 0.75 | 1.90 | 7.87 | 0.21 |
| Home type | House | 31 | 115,600 | 65,970 | 0.14 | 0.20 | 0.56 | 1.49 | 3.17 | 0.014 |
| | Apt. | 35 | 87,140 | 87,060 | 0.08 | 0.19 | 0.96 | 2.48 | 17.79 | 0.99 |
| Sample surface | Rug/carpet | 49 | 105,300 | 81,820 | 0.08 | 0.19 | 0.78 | 1.99 | 9.66 | 0.35 |
| | Multiple[a] | 17 | 84,470 | 62,780 | 0.18 | 0.21 | 0.65 | 1.87 | 3.53 | 0.30 |

Abbreviations: GM, geometric mean; Q, percentile.
[a]Rugs, carpets, smooth surfaces, and bedding.

**Table 5.** Parameter estimates, 95% confidence intervals, and $P$-values for mixed models exploring the effect of prior cleaning and prior education on change in baseline cat, cockroach, and fungal allergen levels.

| Allergen | Intervention | Parameter[a] Estimate | 95% CI Lower | 95% CI Upper | Pr > \|t\| |
|---|---|---|---|---|---|
| Cat | Prior cleaning | 0.223 | 0.094 | 0.529 | 0.001 |
| | Prior education | 0.389 | 0.226 | 0.670 | 0.001 |
| | Prior cleaning and education | 0.350 | 0.185 | 0.660 | 0.001 |
| | No prior intervention | Reference | | | |
| Cockroach | Prior cleaning | 0.704 | 0.377 | 1.316 | 0.270 |
| | Prior education | 0.718 | 0.485 | 1.062 | 0.097 |
| | Prior cleaning and education | 1.280 | 0.808 | 2.027 | 0.291 |
| | No prior intervention | Reference | | | |
| Fungus | Prior cleaning | 0.414 | 0.174 | 0.983 | 0.046 |
| | Prior education | 0.532 | 0.311 | 0.910 | 0.021 |
| | Prior cleaning and education | 0.754 | 0.399 | 1.423 | 0.382 |
| | No prior intervention | Reference. | | | |

[a]Exponent of parameter estimates.

allergens associated with the causation and exacerbation of asthma, as there were nonsignificant changes in cat allergen levels in homes with or without cats, and no significant change in cockroach allergen levels. Both prior cleaning and prior education had similar-sized effects on reducing baseline levels in pre-intervention samples for subsequent visits during the intervention phase of this trial, indicating that cleaning and education were about equally effective in reducing allergen levels over time during the intervention phase of this study. Overall, these results indicate a modest reduction in common asthma triggers with implementation of this protocol.

Another way to evaluate the effectiveness of the interventions as well as the range of allergen concentrations observed in this study is to compare them to suggested health benchmarks and levels observed in other studies. The suggested health benchmarks for each allergen type are $>8\,\mu g/g$ for cat (acute symptoms), $>2\,U/g$ for cockroach sensitization, $>2\,\mu g/g$ for dust mite sensitization, and $\geqslant 10^5$ CFU for fungi (NRC, 2000; HUD, 2001; Ramachandran et al., 2005). Overall, the percentage of nonintervention (home visits 1–3) and pre-intervention samples (home visits 4–6) greater than the cat allergen benchmark, 21%, was similar to levels observed by Leaderer et al. (2002) (21%), but lower than the ~35% observed in Arbes et al.'s (2004) recent national study. Restricting this analysis to intervention visit homes indicates that the percent of samples above the cat allergen threshold was not changed substantially by the cleaning intervention. In homes with cats, 85% of pre-intervention and 77% of post-intervention samples were above the health benchmark, which is in sharp contrast to the 4% of pre- and 2% of post-intervention samples above the benchmark for non-cat homes.

In this study, the percentage of nonintervention and pre-intervention samples with dust mite levels greater than the threshold was 11%, which is lower than was observed in the National Cooperative Inner City Asthma Study (NCICAS) and other studies in both low and higher income communities (Rosenstreich et al., 1997; Chew et al., 1999; Kitch et al., 2000; Leaderer et al., 2002). Our dust mite levels were lower than levels observed in our previous studies in this neighborhood, and thus our results are likely affected by measurement bias, because our QA/QC samples indicate that dust mite results were biased low by approximately 40–50%. The low levels observed in this study may also reflect the actual absence of dust mites: anecdotal reports indicate that Minneapolis is at the northern edge of the natural range of Der f1 and Der p1.

Twenty-four percent of samples had cockroach levels greater than the threshold, which was lower than observed in high-rise urban apartment buildings in NCICAS (85%), but overall levels were in the same range as other studies in homes in the northeast US (Rosenstreich et al., 1997; Chew et al., 1999; Kitch et al., 2000; Leaderer et al., 2002). The cockroach levels observed in this study were also lower than in our previous study in neighborhood schools and homes, but this may reflect measurement bias indicated by our QA/QC results (Ramachandran et al., 2005; Greaves et al., 2007). Restricting the analysis to intervention visits indicates that the intervention modestly reduced the percent of samples above the cockroach allergen threshold: 24% of pre-intervention and 13% of post-intervention samples had concentrations above the health benchmark.

The cleaning intervention significantly reduced fungal levels in single family homes but not in apartments. This result may be partially attributed to considerably higher baseline levels in single family homes compared to apartments, although this observed difference does not appear to be an artifact and likely reflects reality in these environments. Nevertheless, 55% of study samples had fungal levels above the health-based threshold, with clear seasonal variability (Cho et al., 2007). Analysis of pre- *versus* post-intervention samples indicated that the cleaning intervention modestly reduced the percentage of samples above the threshold, from 44% to 35%. There is less data to characterize the prevalence of elevated fungal levels in residences and evaluate the meaning of these results, although there is increasing research in this area (IOM, 2004; Ramachandran et al., 2005). Ongoing work exploring the variability in allergen levels over time as well as fungal speciation will further explore the implications of these results.

The significant reduction in overall dust loading due to the cleaning intervention is probably the most important result of this study. The preponderance of the scientific literature indicates that individual allergens are the most important risk factors, but a recent study performed in a large number of households also concludes that dust loading is an independent risk factor for asthma (Elliott et al., 2007; Wu and Takaro, 2007). A lack of reduction, and in some cases increases in cat allergen levels in both cat and non-cat homes, may be explained in part by noting that cat allergen is known to be difficult to remove, and the effect of the intervention may have been to reduce the amount of nonallergen-containing dust present in the post-sample, thereby reducing the denominator (dust mass collected) and increasing the observed cat allergen concentration if the cat allergen removal rate remains the same (Eggleston and Wood, 1992). The nonsignificant changes in cockroach levels still resulted in a halving of the number of homes with levels above thresholds of clinical significance.

Although some studies have indicated that education alone is an effective intervention, the preponderance asthma intervention studies indicate that education alone has not been effective in changing parental behaviors that affect asthma risk factors (Krieger et al., 2005; Wu and Takaro, 2007). While our results do not markedly change this conclusion, it is notable during the intervention phase of this study that the short-term (6 weeks to 4 months) effect of education was indistinguishable from the effect of cleaning on allergen levels in subsequent pre-cleaning samples. Given our study design, which had repeat measures and no true control group in the classic sense, it is also possible that the act of participation in this study can also be a potential source of the observed effect on baseline allergen levels.

The other limitations of this study are a population comprised of families with and without an asthmatic, relatively small sample size, the use of pre- *versus* post-comparisons, and the low percentage of detectable dust mite allergens. Although not all study households had a diagnosed asthmatic, the focus of this study was to systematically test interventions thought to reduce asthma causation/exacerbation and that are widely recommended by public health agencies. Asthma rates in the community where this study took place were approximately three times the national average, and nonasthmatic households were aware of the elevated rates in the community (Greaves et al., 2007). In our judgment, this decreases the likelihood that there were any major behavioral differences between the asthmatic and nonasthmatic households that would affect interpretation of these data. Even though our numbers were relatively small, which might have contributed to the nonsignificant difference in some pre- and post-intervention comparisons, this study was as large or larger than several other interventions and Home Allergen Reduction Study (HARS) results indicate that the collection of procedures in this study likely reduce the overall burden of allergens in study homes in a fairly sustainable fashion. As a consequence of the low prevalence of dust mite allergens, we were unable to systematically assess the effectiveness of our interventions in changing dust mite allergen levels. However, given that cat, cockroach, and fungal spores are in the same general particle size range as dust mites, it seems likely that the intervention would at least reduce dust mite loadings above health benchmarks if initial levels were more frequently detected. This is one of the first studies to report use of external reference dusts and assess commercial laboratory performance over time. The availability of certified external standards for house dust allergens to conduct blinded assessment of analytical performance has not been routinely reported in past studies in the literature, and our results highlight the importance of incorporating these procedures into future studies because it appears that commercial laboratory performance can vary widely.

The primary strengths of this study are a high retention rate, a randomized design, and community input on the scope of the intervention. Furthermore the intervention, which was designed in consultation with community members in the process of planning and implementing the study, uses commonly available tools and resources, can be done in 1–2 h in most residences, and requires little additional training. Overall, the net effect of the cleaning interventions employed in this study was to reduce the presence of multiple asthma triggers using methods that were feasible for inner city residents from this community. The results of this intervention compare favorably to other more expensive allergen reduction techniques that have been evaluated, but in our judgment are unlikely to be implemented because of the time, cost, and sustainability issues associated with their use. The 1-year follow-up for this study was not adequate to establish sustainability or optimal cleaning intervals for these interventions, so future research should assess these issues as well as their effect on asthma mortality and morbidity.

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## References

Arbes Jr S.J., Cohn R.D., Yin M., Muilenberg M.L., Friedman W., and Zeldin D.C. Dog allergen (Can f 1) and cat allergen (Fel d 1) in US homes: results from the National Survey of Lead and Allergens in Housing. *J Allergy Clin Immunol* 2004: 114(1): 111–117.

Carter M.C., Perzanowski M.S., Raymond A., and Platts-Mills T.A. Home intervention in the treatment of asthma among inner-city children. *J Allergy Clin Immunol* 2001: 108(5): 732–737.

Chan-Yeung M., Ferguson A., Watson W., Dimich-Ward H., Rousseau R., Lilley M., Dybuncio A., and Becker A. The Canadian Childhood Asthma Primary Prevention Study: outcomes at 7 years of age. *J Allergy Clin Immunol* 2005: 116(1): 49–55.

Chapman M.D., Heymann P.W., Wilkins S.R., Brown M.J., and Platts-Mills T.A. Monoclonal immunoassays for major dust mite (Dermatophagoides) allergens, Der p I and Der f I, and quantitative analysis of the allergen content of mite and house dust extracts. *J Allergy Clin Immunol* 1987: 80(2): 184–194.

Chew G.L., Higgins K.M., Gold D.R., Muilenberg M.L., and Burge H.A. Monthly measurements of indoor allergens and the influence of housing type in a northeastern US city. *Allergy* 1999: 54(10): 1058–1066.

Cho S., Ramachandran G., Grengs J., Ryan A., Eberly L., and Adgate J.L. Longitudinal evaluation of allergen and culturable fungal concentrations in inner-city households. *J Occup Environ Hyg* 2007 (in press).

Eggleston P.A., and Wood R.A. Management of allergies to animals. *Allergy Proc* 1992: 13(6): 289–292.

Elliott L., Arbes S., Harvey E., Lee R., Salo P., Cohn R., London S., and Zeldin D. Dust weight and asthma prevalence in the national survey of lead and allergens in houseing (NSLAH). *Environ Health Perspect* 2007: 115: 215–220.

Greaves I.A., Sexton K., Blumenthal M.N., Church T.R., Adgate J.L., Ramachandran G., Fredrickson A.L., Ryan A.D., and Geisser M.S. Asthma, atopy, and lung function among racially diverse, poor inner-urban Minneapolis schoolchildren. *Environ Res* 2007: 103(2): 257–266.

HUD. *Healthy Homes Issues: Asthma*. US Department of Housing and Urban Development, Office of Healthy Homes and Lead Hazard Control, Washington, DC, 2001.

IOM. *Damp Indoor Spaces and Health*. National Academies Press, Washington, DC, 2004.

Israel B.A., Schulz A.J., Parker E.A., and Becker A.B. Review of community-based research: assessing partnership approaches to improve public health. *Annu Rev Public Health* 1998: 19: 173–202.

Kitch B.T., Chew G., Burge H.A., Muilenberg M.L., Weiss S.T., Platts-Mills T.A., O'Connor G., and Gold D.R. Socioeconomic predictors of high allergen levels in homes in the greater Boston area. *Environ Health Perspect* 2000: 108(4): 301–307.

Krieger J.W., Takaro T.K., Song L., and Weaver M. The Seattle-King County Healthy Homes Project: a randomized, controlled trial of a community health worker intervention to decrease exposure to indoor asthma triggers. *Am J Public Health* 2005: 95(4): 652–659.

Leaderer B.P., Belanger K., Triche E., Holford T., Gold D.R., Kim Y., Jankun T., Ren P., McSharry Je J.E., Platts-Mills T.A., Chapman M.D., and Bracken M.B. Dust mite, cockroach, cat, and dog allergen concentrations in homes of asthmatic children in the northeastern United States: impact of socioeconomic factors and population density. *Environ Health Perspect* 2002: 110(4): 419–425.

Levy J.I., Brugge D., Peters J.L., Clougherty J.E., and Saddler S.S. A community-based participatory research study of multifaceted in-home environmental interventions for pediatric asthmatics in public housing. *Soc Sci Med* 2006: 63(8): 2191–2203.

Morgan W.J., Crain E.F., Gruchalla R.S., O'Connor G.T., Kattan M., Evans III R., Stout J., Malindzak G., Smartt E., Plaut M., Walter M., Vaughn B., and Mitchell H. Results of a home-based environmental intervention among urban children with asthma. *N Engl J Med* 2004: 351(11): 1068–1080.

NRC. *Clearing the Air: Asthma and Indoor Air Exposures*. National Academy Press, Washington, D.C, 2000.

NRC/IOM. *Ethical Considerations For Research on Housing-Related Health Hazards Involving Children*. National Academies Press, Washington, DC, 2005.

Ramachandran G., Adgate J.L., Banerjee S., Church T.R., Jones D., Fredrickson A., and Sexton K. Indoor air quality in two urban elementary schools — measurements of airborne fungi, carpet allergens, CO2, temperature, and relative humidity. *J Occup Environ Hyg* 2005: 2(11): 553–566.

Rosenstreich D.L., Eggleston P., Kattan M., Baker D., Slavin R.G., Gergen P., Mitchell H., McNiff-Mortimer K., Lynn H., Ownby D., and Malveaux F. The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *N Engl J Med* 1997: 336(19): 1356–1363.

Sexton K., Greaves I.A., Church T.R., Adgate J.L., Ramachandran G., Tweedie R.L., Fredrickson A., Geisser M., Sikorski M., Fischer G., Jones D., and Ellringer P. A school-based strategy to assess children's environmental exposures and related health effects in economically disadvantaged urban neighborhoods. *J Expo Anal Environ Epidemiol* 2000: 10(6 Part 2): 682–694.

Swartz L.J., Callahan K.A., Butz A.M., Rand C.S., Kanchanaraksa S., Diette G.B., Krishnan J.A., Breysse P.N., Buckley T.J., Mosley A.M., and Eggleston P.A. Methods and issues in conducting a community-based environmental randomized trial. *Environ Res* 2004: 95(2): 156–165.

Takaro T.K., Krieger J.W., and Song L. Effect of environmental interventions to reduce exposure to asthma triggers in homes of low-income children in Seattle. *J Expo Anal Environ Epidemiol* 2004: 14(Suppl 1): S133–S143.

Vojta P.J., Randels S.P., Stout J., Muilenberg M., Burge H.A., Lynn H., Mitchell H., O'Connor G.T., and Zeldin D.C. Effects of physical interventions on house dust mite allergen levels in carpet, bed, and upholstery dust in low-income, urban homes. *Environ Health Perspect* 2001: 109(8): 815–819.

Wood R.A., Eggleston P.A., Lind P., Ingemann L., Schwartz B., Graveson S., Terry D., Wheeler B., and Adkinson Jr N.F. Antigenic analysis of household dust samples. *Am Rev Respir Dis* 1988: 137(2): 358–363.

Wu F., and Takaro T.K. Childhood asthma and environmental interventions. *Environ Health Perspect* 2007: 115, (doi:10.1289/ehp.8989, online January 25, 2007) 971–975.