Evaluation of the Environmental Scoring System in Multiple Child Asthma Intervention Programs in Boston, Massachusetts

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Objectives. To test the applicability of the Environmental Scoring System, a quick and simple approach for quantitatively measuring environmental triggers collected during home visits, and to evaluate its contribution to improving asthma outcomes among various child asthma programs.

Methods. We pooled and analyzed data from multiple child asthma programs in the Greater Boston Area, Massachusetts, collected in 2011 to 2016, to examine the association of environmental scores (ES) with measures of asthma outcomes and compare the results across programs.

Results. Our analysis showed that demographics were important contributors to variability in asthma outcomes and total ES, and largely explained the differences among programs at baseline. Among all programs in general, we found that asthma outcomes were significantly improved and total ES significantly reduced over visits, with the total Asthma Control Test score negatively associated with total ES.

Conclusions. Our study demonstrated that the Environmental Scoring System is a useful tool for measuring home asthma triggers and can be applied regardless of program and survey designs, and that demographics of the target population may influence the improvement in asthma outcomes. (*Am J Public Health.* 2018;108:103–111. doi:10.2105/AJPH.2017.304125)

See also Gracy, p. 21.

Asthma is the most common chronic disease among children in the United States, currently affecting about 8.6% of children (aged < 18 years) or more than 6 million children.[1] According to the Centers for Disease Control and Prevention, Massachusetts has the highest current asthma prevalence in adults of all states in the United States.[2] It is also among the highest in percentage of children with uncontrolled asthma (41%), which is associated with emergency department (ED) visits, hospitalization rates, and absenteeism from school.[3]

Previous research has established that exposures to endotoxins and indoor allergens commonly found in urban home environments, such as dust, pests, pets, and mold, are strong risk factors for the development of childhood asthma.[4,5] Therefore, the National Institutes of Health recommends the control of environmental factors as a needed component of asthma management.[6]

There are significant disparities in asthma burdens among demographic and socioeconomic groups. Higher asthma prevalence is commonly found in minority groups such as Blacks or Hispanics, and in populations with lower socioeconomic status.[7] In addition, Black and Hispanic children tend to have more severe asthma and lower utilization of preventive medication than White children, even after adjustment for socioeconomic status.[8] However, there is evidence that asthma disparities can be substantially reduced by comprehensive care, both through the health care system and through home-based intervention programs.[9]

Numerous asthma intervention programs have been developed throughout the United States based on clinical and environmental intervention studies. Many of these programs have been shown to improve asthma outcomes in children,[10] especially those conducted by community health workers and focusing on home-based interventions.[11–13] However, studies to date have mostly focused on clinical outcomes, whereas few have examined these programs in practice[14] or

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compared the efficiency of environmental interventions among different programs.

There are several completed or ongoing large child asthma intervention programs in the Greater Boston Area, Massachusetts. Among these programs is the Boston Asthma Home Visit Collaboration (BAHVC, 2010–present), which convenes the asthma programs serving Boston residents, including the Boston Public Health Commission Asthma Home Visit Program (BPHC), Boston Children's Hospital Community Asthma Initiative (CAI),[9,15–17] and Tufts Medical Center Floating Hospital for Children Asthma Prevention and Management Initiative (Tufts). There is also the New England Asthma Innovations Collaborative (2012–2015) led by Health Resources in Action/Asthma Regional Council of New England,[18] and New England Asthma Innovations Collaborative's New England Working to Reducing Ethnic/Racial Asthma Disparities in Youth (NEW READY, 2010–2014) program led by Health Resources in Action in collaboration with the Boston Medical Center (BMC). These programs vary in specific goals, populations, and inclusion criteria, but all aim at improving asthma outcomes and reducing environmental asthma triggers in homes, and utilize community health workers to provide home-based asthma education to parents of children with asthma in a series of home visits, with a shared interest in reaching out to different ethnic/racial and socioeconomic groups to reduce disparities in burden and care of asthma.

As a quick and simple approach to quantitatively assess home asthma triggers collected during home visits, the Massachusetts Department of Public Health developed the Environmental Scoring System (ESS).[19] It is a composite score ranging from 0 to 6, a sum of 6 indicators each representing 1 of 6 key asthma triggers—dust, mold, pests, smoke, pets, and chemicals—with a lower score indicating fewer asthma triggers present in the home. Each indicator is a binary score of 0 or 1 based on the parental report of exposure to a trigger and the community health workers' observations on the evidence of the trigger in the home. Preliminary data from the Massachusetts Department of Public Health showed a significant decrease in the composite score at the end of the visits from baseline,[19] suggesting the potential value of this approach. However, given the large variability in the implementation of specific asthma programs and design of survey questions to collect information on asthma triggers, it is unclear whether ESS would be a good approach for measuring environmental triggers and predicting asthma outcomes across different programs and populations.

The purpose of the study was to prospectively evaluate ESS as a new tool for applicability and to predict validity across several different asthma programs in the Greater Boston Area. All programs share a multisession home visiting model to identify and decrease environmental triggers. The diversity of settings, staffing, populations, and administration across these programs provides an opportunity to test whether the ESS tools have broad applicability. To evaluate the use of ESS in these settings, we summarized and compared demographics of populations under all asthma programs, and applied ESS to construct environmental scores (ES) in each data set. We then summarized changes in ES in each of the cohorts. Finally, we examined correlations between the ES generated by these different programs and outcomes related to status of asthma management, including Asthma Control Test (ACT) and ED visits. Our results can provide valuable insights for future intervention programs in large cities and improve our understanding of the associations between environmental triggers and asthma outcomes.

METHODS

We compiled 6 data sets of BAHVC (2 each from BPHC, CAI, and Tufts) and 1 data set from BMC (NEW READY) for statistical analyses both within and across programs. Each program within BAHVC aimed for 3 home visits and used a standardized set of core questions developed collaboratively by the programs, whereas BMC aimed for 5 home visits and used its own survey instruments, but all programs collected data on key environmental triggers. Therefore, we performed data analysis for BMC separately and included the results in the material available as a supplement to the online version of this article at http://www.ajph.org, together with a brief description of these 2 questionnaires. All questionnaires used by the programs were designed to obtain information about children (defined as aged between 2 and 18 years at enrollment) with asthma (referred to as "participants" hereafter), although they were completed by the parents or guardians. Home visitors from all the programs attended a standardized training offered through a community health worker training center, and environmental walkthrough was practiced as part of the training.

Calculating the Environmental Scores

For the BAHVC data sets, we calculated total ES as the sum of 6 binary scores (i.e., mold, pet, pest, smoke, dust, and chemical scores), each of which we defined as 1 if any of the questions related to the presence of that environmental trigger were checked and 0 otherwise. Among the 6 scores, we based smoke and pet scores only on self-reported questions as they were not included in the Home Visit Observations form.

To evaluate the contribution of self-reports versus home observations to the calculation of ES, we also calculated ES by using home observations only for indices based in part on direct observation (ES_{obs}). Specifically, mold, pest, dust, and chemical scores excluded information from the Resident Report and only included information from the Home Visit Observations form. We then calculated total ES_{obs} as the sum of the 4 updated scores and the original pet and smoke scores (which only relied on self-reported data). Detailed information on how to construct the ES is included in the material available as a supplement to the online version of this article at http://www.ajph.org.

Data Analyses

We used total ACT score and number of ED visits in the past 6 months as our primary asthma outcome variables. The ACT is a commonly used test[20] for determining if patients' asthma symptoms are well-controlled (ACT > 19).[21] The ACT score was derived on the basis of a series of 6 questions on the severity of asthma symptoms over the past 4 weeks.

We calculated demographic composition (in percentages of population) from each data set regarding age, ethnicity, preferred language, and parent education. We calculated mean and standard deviations of total ACT score, ED visits, and ES at each visit for each program, and we tested the statistical difference for each outcome variable between visit 2 or 3 and visit 1 by using the Wilcoxon signed-rank test. To determine if substantial selection bias arose from loss to follow-ups, we did these analyses only for participants who participated in all visits as well as for all participants.

For the merged BAHVC data set, we regressed total ACT score against total ES or ES_{obs} by using a mixed-effects model, in which a participant was designated as a random intercept to account for within-participant variability over visits. The model either only accounted for visit and program (unadjusted model), or additionally accounted for age, race/ethnicity, and parent education level (adjusted model). We tested a program-by-visit interaction term in both models to explore and compare trends over visits in each program.

We performed all statistical analyses in RStudio version 0.99.902 with R version 3.3.0 (R Foundation, Vienna, Austria).

RESULTS

Demographics for all participants varied across programs (Table 1; Figure A, available as a supplement to the online version of this article at http://www.ajph.org). Overall, there were fewer preschoolers in CAI, a larger proportion of Asian participants in Tufts, and higher percentages of Hispanic/Latino or Spanish-speaking participants in CAI and BMC. Parent education levels for BMC participants were the lowest among all data sets, followed by Tufts participants.

Demographic patterns among participants who stayed through all visits were generally similar to those among all participants (Table 1; Figure A, available as a supplement to the online version of this article at http://www.ajph.org), suggesting little bias attributable to loss to follow-up. Among all programs, Tufts had the highest completion rates, followed by CAI. The better completion rate and higher proportion of Asians in the Tufts program may be because it was located within the Asian clinic, which facilitated translation and other services for Asians.

Trends Over Visits

Among all participants, total ACT scores on average increased over successive visits, whereas ED visits and ES generally decreased (Figure 1), suggesting the effectiveness of asthma interventions in all programs. However, the magnitude and statistical significance (Table A, available as a supplement to the online version of this article at http://www.ajph.org) of the changes varied among programs. Over the 3 home visits, the increase in total ACT score was significant ($P < .001$) in CAI and Tufts but not in BPHC (probably because of BPHC's small sample size), the decrease in ED visits was significant ($P < .001$) in all programs, and the decrease in total ES was significant ($P < .01$) in BPHC and CAI but not in Tufts. In CAI, total ES increased between visit 2 and 3, suggesting that some triggers might not have consistently improved over the course of the study.

The significance of changes in total ES was primarily driven by the mold score in BPHC and CAI, indicating that some indices, particularly the mold score, may better characterize the reduction of a trigger or an effect of the program, which may be related to the way the questions were formulated. Nevertheless, total ES was able to capture the overall variability in environmental triggers over visits regardless of the performance of each individual score. In addition, most scores in CAI showed significant changes over visits, indicating that the performance of all indices may improve with a larger sample size.

Among participants who participated in all visits, the trends in total ACT score, ED visits, and ES closely followed those for all participants (Figure 1; Table A, available as a supplement to the online version of this article at http://www.ajph.org), again suggesting little bias attributable to loss to follow-ups. Despite the substantial reduction in sample size, differences over visits remained significant.

The percentage of participants with well-controlled asthma also increased consistently over 3 visits (Figure B, available as a supplement to the online version of this article at http://www.ajph.org) except in Tufts, which had a trend similar to the total ACT score and decreased slightly after visit 2. Those who participated in all visits followed the same pattern, except that in BPHC a much higher percentage (38.9% vs 25.8%) of these participants already had well-controlled asthma at visit 1.

Environmental Scores From Home Observations Only

On average, total ES_{obs} was 2 units smaller than total ES—that is, self-reports combined with home observations generally included 2 more triggers than home observations only. This was mainly attributable to fewer questions contributing to the scoring of total ES_{obs} and reducing the likelihood for a score to be 1. Moreover, total ES_{obs} showed more consistent decreasing trends over subsequent visits than total ES (Table B and Figure C, available as supplements to the online version of this article at http://www.ajph.org), especially in Tufts and CAI, suggesting that it may be a more responsive measure of the intervention effect.

Outcomes Stratified by Demographics, Visit, and Program

Average total ACT score was significantly higher in children aged 9 to 13 years, and lower in preschoolers and adolescents (Table 2). It was highest in Asian participants (20.4) and lowest in White participants (15.2), and varied little over parent education levels. Over the 3 visits, total ACT score increased steadily from 16.4 to 20.5. Among programs, average total ACT score (across all visits) ranged from 13.1 in BPHC to 19.9 in Tufts. Only CAI and Tufts showed significant increases over visits, although BPHC had the lowest total ACT score at baseline.

The number of ED visits generally followed patterns consistent with the total ACT score but the differences were not significant among age, race/ethnicity, or education groups. There were significant differences in ED visits among the 3 programs at baseline, but all 3 programs showed significant decreases over visits.

Total ES and ES_{obs} had similar patterns across demographic groups. There was no significant trend among age and education groups, but White participants had significantly higher scores than the other race/ethnicity groups. Total ES was significantly lower

TABLE 1—Demographic Composition Among All Participants and Those Who Stayed Through All 3 Visits in All 4 Asthma Programs Evaluated: Greater Boston Area, MA, 2011–2016

	BPHC		CAI		Tufts		BMC	
Group/Levels	All, No. (%)	No Dropouts, No. (%)	All, No. (%)	No Dropouts, No. (%)	All, No. (%)	No Dropouts, No. (%)	All, No. (%)	No Dropouts, No. (%)
Age at enrollment, y								
0–5	88 (53.3)	30 (50.8)	241 (39.8)	116 (43.6)	117 (61.6)	55 (53.4)	89 (52.0)	34 (52.3)
6–8	36 (21.8)	15 (25.4)	156 (25.7)	70 (26.3)	33 (17.4)	26 (25.2)	46 (26.9)	19 (29.2)
9–13	31 (18.8)	13 (22.0)	157 (25.9)	64 (24.1)	30 (15.8)	20 (19.4)	30 (17.5)	11 (16.9)
> 13	10 (6.1)	1 (1.7)	52 (8.6)	16 (6.0)	10 (5.3)	2 (1.9)	6 (3.5)	1 (1.5)
Race/ethnicity[a]								
Hispanic/Latino	28 (15.7)	11 (16.7)	330 (52.6)	149 (55.4)	8 (6.5)	3 (3.1)	140 (46.4)	53 (46.9)
White	24 (13.5)	12 (18.2)	6 (1.0)	2 (0.7)	7 (5.6)	3 (3.1)	35 (11.6)	17 (15.0)
Black	106 (59.6)	40 (60.6)	271 (43.2)	109 (40.5)	33 (26.6)	20 (20.8)	33 (10.9)	15 (13.3)
Asian/Pacific Islander	3 (1.7)	0 (0.0)	3 (0.5)	2 (0.7)	75 (60.5)	70 (72.9)	4 (1.3)	0 (0.0)
AI/AN	1 (0.6)	0 (0.0)	4 (0.6)	3 (1.1)	0 (0.0)	0 (0.0)	3 (1.0)	2 (1.8)
Other	12 (6.7)	2 (3.0)	12 (1.9)	3 (1.1)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)
Declined to answer	4 (2.2)	1 (1.5)	1 (0.2)	1 (0.4)	0 (0.0)	0 (0.0)	87 (28.8)	26 (23.0)
Preferred language								
English	147 (81.2)	55 (82.1)	392 (68.2)	175 (65.5)	55 (40.1)	27 (28.1)	53 (31.0)	18 (27.7)
Spanish	26 (14.4)	7 (10.4)	175 (30.4)	89 (33.3)	4 (2.9)	2 (2.1)	126 (73.7)	52 (80.0)
Chinese	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	76 (55.5)	66 (68.8)	0 (0.0)	0 (0.0)
Haitian Creole	4 (2.2)	1 (1.5)	2 (0.3)	1 (0.4)	0 (0.0)	0 (0.0)	1 (0.6)	1 (1.5)
Cape Verdean Creole	0 (0.0)	0 (0.0)	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Portuguese	2 (1.1)	1 (1.5)	1 (0.2)	1 (0.4)	0 (0.0)	0 (0.0)	5 (2.9)	4 (6.2)
Other	1 (0.6)	1 (1.5)	4 (0.7)	1 (0.4)	2 (1.5)	1 (1.0)	8 (4.7)	3 (4.6)
Declined/unavailable	1 (0.6)	1 (1.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Highest education								
Did not attend school	0 (0.0)	0 (0.0)	2 (0.3)	1 (0.4)	0 (0.0)	0 (0.0)	4 (2.3)	1 (1.5)
≤ eighth grade	2 (1.1)	1 (1.5)	11 (1.9)	5 (1.9)	13 (10.8)	9 (10.3)	53 (31.0)	21 (32.3)
Some high school	22 (12.2)	7 (10.4)	84 (14.7)	44 (16.7)	19 (15.8)	11 (12.6)	31 (18.1)	9 (13.8)
High school or GED	25 (13.8)	9 (13.4)	221 (38.6)	94 (35.6)	42 (35.0)	33 (37.9)	58 (33.9)	24 (36.9)
Some college	64 (35.4)	27 (40.3)	137 (23.9)	60 (22.7)	19 (15.8)	11 (12.6)	22 (12.9)	10 (15.4)
College or grad school	24 (13.3)	7 (10.4)	41 (7.2)	13 (4.9)	10 (8.3)	10 (11.5)	2 (1.2)	0 (0.0)
Other	7 (3.9)	3 (4.5)	5 (0.9)	1 (0.4)	2 (1.7)	1 (1.1)	0 (0.0)	0 (0.0)
Declined/unavailable	37 (20.4)	13 (19.4)	72 (12.6)	46 (17.4)	15 (12.5)	12 (13.8)	1 (0.6)	0 (0.0)
Total no.[b] (% completion)	189	67 (35.4)	630	269 (42.7)	191	103 (53.9)	171	65 (38.0)

Notes. AI/AN = American Indian/Alaska Native; BMC = Boston Medical Center; BPHC = Boston Public Health Commission Asthma Home Visit Program; CAI = Boston Children's Hospital Community Asthma Initiative; GED = general equivalency diploma; Tufts = Tufts Medical Center Floating Hospital for Children Asthma Prevention and Management Initiative.

[a]Ethnicity and race were asked in 2 different questions but are combined here to achieve a total percentage of 100%. A participant was counted as Hispanic/Latino if they checked this option in the ethnicity question, although they may have also chosen "Other" in the race question.

[b]Total number of participants with a record in each data set, in which some participants may have missing information for certain variables.

at visit 2, but no difference was found between visit 1 and 3, whereas total ES_{obs} decreased steadily over visits. Among the 3 programs, average total ES and ES_{obs} were the lowest in CAI. Compared with visit 1 within each program, BPHC had significantly lower total ES and marginally lower total ES_{obs} at visit 3, CAI had significantly lower total ES at visit 2 whereas total ES_{obs} decreased consistently over all 3 visits, and Tufts only had marginally lower total ES_{obs} at visit 3.

Regression Results

In the unadjusted model (Table 3), total ACT score had a significant inverse relationship with total ES_{obs} but not total ES, with each unit decrease in total ES or total ES_{obs} corresponding to a 0.13 ($P = .12$) or 0.21 ($P = .05$) unit increase in total ACT score. In addition, total ACT score varied among programs and was significantly (about 2.1 units) higher in Tufts than in BPHC at visit 1, suggesting differences in baseline asthma condition among target populations. It increased significantly over subsequent visits in both BPHC and CAI, with the average score at

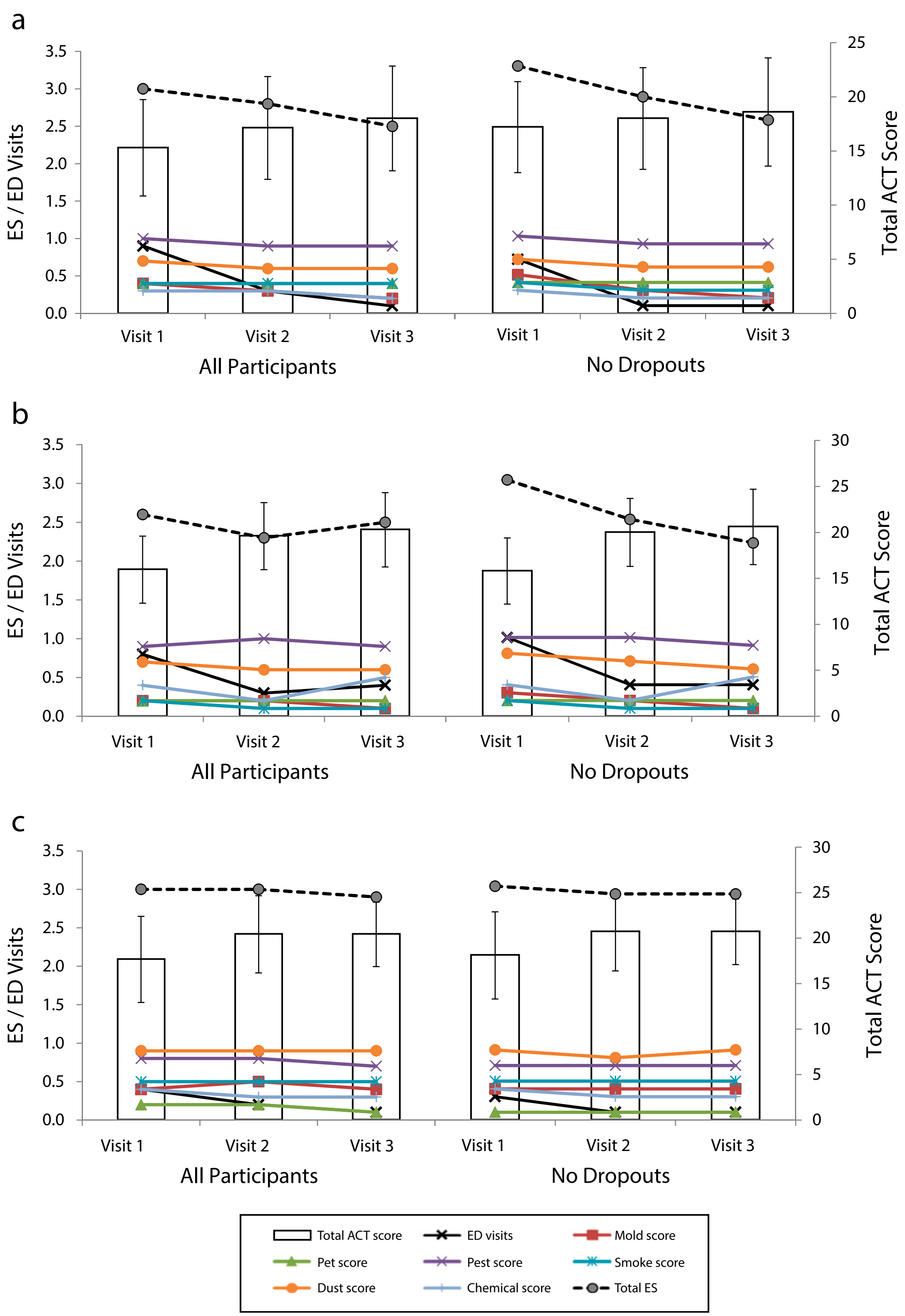

FIGURE 1—Total Asthma Control Test (ACT) Score, Emergency Department (ED) Visits, and Environmental Scores (ES) for All Participants and Those Who Stayed Through All 3 Visits in (a) Boston Public Health Commission Asthma Home Visit Program, (b) the Boston Children's Hospital Community Asthma Initiative, and (c) Tufts Medical Center Floating Hospital for Children Asthma Prevention and Management Initiative: Greater Boston Area, MA, 2011–2016

TABLE 2—Mean and Standard Deviation of Total Asthma Control Test Score, Emergency Department Visits, and Total Environmental Scores Stratified by Groups of Age, Race/Ethnicity, Highest Parent Education, Visit, Program, and Program × Visit in All Participants: Greater Boston Area, MA, 2011–2016

	Total ACT Score		ED Visits		Total ES		Total ES_{obs}	
Group/Levels	No.[a]	Mean (SD)	No.[a]	Mean (SD)	No.[a]	Mean (SD)	No.[a]	Mean (SD)
Age, y								
0–5	768	17.6 (5.8)	854	0.6 (1.1)	928	2.6 (1.3)	928	1.3 (1.0)
6–8	478	18.3 (5.1)	482	0.4 (0.9)	511	2.6 (1.3)	511	1.2 (1.0)
9–13	431	18.7** (4.8)	433	0.4 (1.1)	468	2.5 (1.3)	468	1.2 (1.0)
> 13	113	17.8 (4.4)	115	0.6 (1.1)	130	2.7 (1.5)	130	1.4 (1.1)
Race/ethnicity								
White	67	15.2 (7.1)	77	0.5 (1.0)	82	3.2 (1.3)	82	1.8 (1.1)
Black	759	17.3* (5.8)	788	0.5 (1.1)	856	2.8** (1.4)	856	1.4** (1.0)
Hispanic/Latino	749	18.2*** (4.5)	765	0.6 (1.1)	804	2.3*** (1.2)	804	1.0*** (0.9)
Asian/Pacific Islander	216	20.4*** (4.6)	208	0.2 (0.6)	247	2.6** (1.4)	247	1.3** (1.0)
Other	51	16.2 (6.4)	65	0.7 (1.5)	70	2.7 (1.2)	70	1.4 (1.0)
Highest education								
< high school	65	18.1 (4.8)	69	0.6 (1.0)	72	2.5 (1.2)	72	1.0 (0.9)
High school or GED	842	17.9 (4.9)	852	0.5 (1.1)	907	2.6 (1.3)	907	1.3 (1.0)
Some college	399	17.8 (5.8)	435	0.6 (1.2)	458	2.5 (1.2)	458	1.1 (0.9)
College or grad school	135	17.2 (6.9)	142	0.3 (0.8)	153	2.7 (1.4)	153	1.3 (1.1)
Other	296	18.1 (5.5)	305	0.5 (1.0)	319	2.9 (1.2)	319	1.5** (1.0)
Visit								
Visit 1	803	16.4 (4.1)	879	0.8 (1.2)	965	2.7 (1.3)	965	1.4 (1.1)
Visit 2	491	19.8*** (4.0)	585	0.3*** (0.8)	610	2.5* (1.3)	610	1.2** (1.0)
Visit 3	374	20.5*** (4.1)	440	0.3*** (0.9)	455	2.6 (1.2)	455	1.1*** (0.9)
Program								
BPHC	272	13.8 (8.1)	347	0.5 (1.1)	363	2.9 (1.3)	363	1.4 (1.1)
CAI	1289	18.3*** (4.3)	1270	0.6 (1.1)	1353	2.4*** (1.3)	1353	1.1** (1.0)
Tufts	308	19.9*** (4.6)	340	0.3** (0.6)	407	2.8 (1.4)	407	1.4 (1.1)
Program × visit[b]								
BPHC visit 1	97	15.8 (4.6)	171	0.9 (1.3)	187	3.0 (1.3)	187	1.5 (1.1)
BPHC visit 2	57	17.7 (4.9)	112	0.3*** (1.1)	112	2.8 (1.4)	112	1.3 (1.0)
BPHC visit 3	25	18.6 (5.0)	64	0.1*** (0.5)	64	2.5* (1.4)	64	1.1 (1.0)
CAI visit 1	590	16.2 (3.7)	574	0.8 (1.2)	628	2.6 (1.3)	628	1.3 (1.0)
CAI visit 2	363	19.9*** (3.7)	361	0.3*** (0.8)	373	2.3*** (1.2)	373	1.1** (0.9)
CAI visit 3	284	20.6*** (4.1)	283	0.4*** (1.1)	289	2.5 (1.2)	289	1.0** (0.9)
Tufts visit 1	116	17.9 (4.8)	134	0.4 (0.0)	150	3.0 (1.2)	150	1.7 (1.1)
Tufts visit 2	71	20.7*** (4.3)	112	0.2* (0.6)	125	3.0 (1.2)	125	1.5 (1.1)
Tufts visit 3	65	20.7*** (3.6)	93	0.1** (0.5)	102	2.9 (1.1)	102	1.4 (0.9)

Notes. ACT = Asthma Control Test; BPHC = Boston Public Health Commission Asthma Home Visit Program; CAI = Boston Children's Hospital Community Asthma Initiative; ED = emergency department; ES = environmental score; ES_{obs} = environmental score from home observations; GED = general equivalency diploma; Tufts = Tufts Medical Center Floating Hospital for Children Asthma Prevention and Management Initiative.

[a]Sample size represents data from all visits (i.e., each individual may be counted up to 3 times), except for visit and program × visit.

[b]Reported significance was for comparison with visit 1 within each program.

*$P<.05$; **$P<.01$; ***$P<.001$; P values determined by Tukey's multiple comparisons for analysis of variance with regard to the first level of each variable.

visit 3 more than 2 units higher than at visit 1, demonstrating a large overall effect of the intervention in improving asthma outcomes.

In the adjusted model (Table 3), total ACT score was significantly associated with both total ES and total ES_{obs}, with each unit decrease in total ES or ES_{obs} corresponding to 0.17 ($P=.05$) or 0.28 ($P=.01$) increase in total ACT score on average after we accounted for all other variables, which were slightly larger in magnitude than the unadjusted model. The children aged 6 to 8 years and 9 to 13 years had significantly better health than did those aged 0 to 5 years and older than 13 years. We found no significant difference between White participants and those in other race/ethnicity groups. Moreover, children whose parents had at least some college had significantly better health than those whose parents did not finish high school. The differences in total ACT score among programs at baseline were no longer significant in this model, indicating that they could be explained by differences in demographic composition among these programs. After we accounted for age, race/ethnicity, and parent education, total ACT score increased significantly over visits in BPHC and CAI, and nonsignificantly at visit 2 in Tufts. In both the adjusted and unadjusted models, the intercept had a large coefficient and was significant, suggesting large residual variability unaccounted for by the variables in the models.

DISCUSSION

In this study, we analyzed data from multiple child asthma programs in the Greater Boston Area to evaluate the applicability of ESS in measuring home asthma triggers across programs. All programs studied showed improved asthma outcomes to varying degrees, and the ESS tool appeared to be implementable across programs, showing consistent trends regardless of program and survey designs.

Our results showed that trends in total ES or ES_{obs} captured by the tool were associated with asthma outcomes and highlighted differences across programs. However, total ES or ES_{obs} presented a very small contribution to the variation in total ACT score, which only increased 0.17 per unit decrease in total ES or 0.28 per unit decrease in total ES_{obs}. This suggests that the increase in ACT score was largely attributable to other aspects of the intervention, including increased awareness through asthma education, review and implementation of the asthma action plans,

TABLE 3—Unadjusted and Adjusted Mixed-Effects Regression of Total Asthma Control Test Score Against Total Environmental Score or Total Environmental Score From Home Observation Only in Pooled Boston Asthma Home Visit Collaboration Data With All Participants: Greater Boston Area, MA, 2011–2016

	Coefficient (95% CI)	
Covariates	Model With Total ES	Model With Total ES_{obs}
Unadjusted model[a] (n = 1665)		
Intercept	16.19 (15.23, 17.15)	16.09 (15.23, 16.95)
Total ES	−0.13 (−0.30, 0.04)	−0.21 (−0.41, −0.003)
Program at visit 1 (Ref = BPHC)		
CAI	0.37 (−0.50, 1.24)	0.39 (−0.47, 1.26)
Tufts	2.10 (1.01, 3.18)	2.14 (1.06, 3.23)
Program × visit (Ref = visit 1)		
BPHC home visit 2	1.73 (0.56, 2.91)	1.73 (0.56, 2.90)
BPHC home visit 3	2.30 (0.70, 3.90)	2.31 (0.71, 3.91)
CAI home visit 2	1.94 (0.68, 3.20)	1.95 (0.69, 3.21)
CAI home visit 3	2.11 (0.44, 3.79)	2.06 (0.39, 3.73)
Tufts home visit 2	1.31 (−0.26, 2.87)	1.28 (−0.29, 2.84)
Tufts home visit 3	0.68 (−1.25, 2.60)	0.64 (−1.28, 2.56)
Adjusted model[b] (n = 1472)		
Intercept	14.91 (12.89, 16.94)	14.77 (12.81, 16.74)
Age, y (Ref = 0–5)		
6–8	0.63 (0.07, 1.19)	0.61 (0.04, 1.17)
9–13	0.96 (0.38, 1.55)	0.95 (0.37, 1.53)
> 13	0.39 (−0.53, 1.31)	0.43 (−0.49, 1.35)
Race/ethnicity (Ref = White)		
Black	−0.06 (−1.51, 1.39)	−0.07 (−1.53, 1.38)
Hispanic/Latino	−0.12 (−1.61, 1.37)	−0.16 (−1.65, 1.33)
Asian/Pacific Islander[c]	1.10 (−0.69, 2.88)	1.04 (−0.74, 2.83)
Other	−0.53 (−2.55, 1.50)	−0.54 (−2.57, 1.50)
Parent education (Ref < high school)		
High school or GED	1.21 (−0.11, 2.53)	1.26 (−0.06, 2.58)
Some college	2.08 (0.71, 3.45)	2.11 (0.73, 3.48)
College or grad school	2.37 (0.83, 3.90)	2.39 (0.85, 3.92)
Other	1.93 (0.52, 3.34)	2.00 (0.59, 3.41)
Total ES	−0.17 (−0.35, −0.0003)	−0.28 (−0.49, −0.06)
Program at visit 1 (Ref = BPHC)		
CAI	−0.12 (−1.08, 0.85)	−0.08 (−1.04, 0.88)
Tufts	0.43 (−0.98, 1.84)	0.49 (−0.92, 1.91)
Program × visit (Ref = visit 1)		
BPHC home visit 2	1.99 (0.71, 3.28)	2.01 (0.73, 3.30)
BPHC home visit 3	2.11 (0.31, 3.91)	2.13 (0.34, 3.93)
CAI home visit 2	1.89 (0.52, 3.26)	1.87 (0.50, 3.24)
CAI home visit 3	2.61 (0.75, 4.48)	2.53 (0.67, 4.40)
Tufts home visit 2	1.54 (−0.13, 3.22)	1.49 (−0.18, 3.16)
Tufts home visit 3	1.17 (−0.93, 3.28)	1.12 (−0.98, 3.22)

Note. ACT = Asthma Control Test; BPHC = Boston Public Health Commission Asthma Home Visit Program; CAI = Boston Children's Hospital Community Asthma Initiative; CI = confidence interval; ED = emergency department; ES = environmental score; ES_{obs} = environmental score from home observations; GED = general equivalency diploma; Tufts = Tufts Medical Center Floating Hospital for Children Asthma Prevention and Management Initiative.

[a]Total ACT score = intercept + total ES + program × visit.

[b]Total ACT score = intercept + age + race/ethnicity + parent education + total ES + program × visit.

[c]Difference significant between Asian/Pacific Islander and Black (*P* < .01), and between Asian/Pacific Islander and Hispanic/Latino (*P* < .01).

reference to health care providers, better adherence to medication regimens, and supplies provided for eliminating allergens. There could also be changes in environmental conditions not easily captured by the ESS, such as better ventilation and more frequent cleaning. Nevertheless, previous research[22] suggests that ACT changes of 3 or greater are clinically relevant. More than half (54%) of our participants who participated in all 3 visits had an increase in total ACT score of 3 or higher over the visits, suggesting that these programs and improvements in environmental triggers can together provide improvement in this range.

Some of the variance in effectiveness across the programs appeared to be related to demographic differences in the target populations. For example, the smoke score was the highest in Tufts among programs at visit 1 and remained high at visit 3. This is consistent with higher prevalence of cigarette smoking found in male Chinese immigrants,[23] who constitute a large percentage of the Tufts participants' parents. Therefore, offering culturally appropriate smoking cessation programs in Chinese may be the most effective way to reduce environmental triggers of asthma in such households. In addition, approximately half of all participants in CAI and BMC were Hispanic/Latino, compared with about 15% in BPHC and less than 10% in Tufts. It has been shown that asthma prevalence and severity may differ among Hispanic/Latino subpopulations in the United States, such as between Puerto Ricans and Mexican Americans, because of genetic diversity and socioeconomic variation.[24] In Boston, the Hispanic population is predominantly Puerto Rican (28%) and Dominican (24%), with relatively few Mexicans (5%).[25] We did not find any difference in total ACT score between Puerto Rican participants and other Hispanic/Latino participants ($P > .3$ for 2-sample t test at each visit), likely because of missing information in specific ethnic origin for a large percentage (32%) of the participants. Overall, the demographic variables were important contributors to variability in total ACT score, ED visits, and total ES or ES_{obs}, and characterized the differences in asthma outcomes and environmental triggers among programs at baseline.

Among the 6 scores, the mold score was found to be a key driver of the variability in total ES or ES_{obs}, and represented one of the most significant reductions in asthma triggers from the interventions. This may be because mold was easier to both identify and eliminate compared with other triggers such as pet, dust, or smoking, which require more behavioral modification. Pest and chemical scores were the main drivers of ES variability in BMC (Table C, available as a supplement to the online version of this article at http://www.ajph.org), probably for the same reason. This suggests that future interventions to eliminate environmental asthma triggers may achieve better results if targeted toward these specific triggers.

We found that ES_{obs} showed similar decreasing trends over home visits to ES. However, ES_{obs} may be a more robust measure of environmental triggers as it tends to demonstrate a more significant decrease in cases in which the regular ES failed to capture changes over visits. The visual clues of a trigger usually better represent the presence of the trigger and are less affected by recall bias than self-reports. Nevertheless, self-reports provide extra information and are less costly to implement; therefore, it is unlikely that the added robustness of home observations would justify its replacement of self-reported surveys in future programs.

Limitations

Loss to follow-up was a common problem across programs. For example, only 35% of the BPHC participants stayed through all 3 home visits. There was no difference in total ACT score at visit 1 between participants who stayed through all 3 visits and those who dropped out at subsequent visits ($P = .86$), suggesting that the dropouts were not caused by the severity of disease. Among all programs, Tufts had the lowest dropout rate, potentially because of the integration of the community health workers physically and organizationally into the general pediatric clinics (Margaret Reid, e-mail communication, February 12, 2016). Because ESS performed better with a larger sample size (as in CAI), future research is needed on program designs that would lead to higher compliance. Nevertheless, our analyses showed that there was not much difference in results between participants who stayed and those who dropped out, suggesting little bias from the missing data.

Public Health Implications

The integration and comparison of data from multiple programs collected by different survey tools represents a major strength of this study and provides meaningful insights to the applicability of the ESS. Our analysis showed that the approach of addressing environmental triggers through home visits worked, but only partially, and should be implemented along with other types of asthma care and education, and that target population demographics would make a difference. Given the practical difficulty to standardize survey designs and other elements among programs, ESS would be a useful tool that may be applied broadly to different programs in the future. AJPH

CONTRIBUTORS

Z. Dong performed the data analysis and wrote the article. G. Adamkiewicz and M. Reid (equal contribution) co-led the project leading to this article and provided key guidance and concepts for this article. A. Nath led the collaborative effort for data collection, transfer, and analysis. J. Guo developed the Environmental Scoring System and provided insights for its application. U. Bhaumik, M. Y. Chin, S. Dong, E. Marshall, J. S. Murphy, M. T. Sandel, S. J. Sommer, W. W. S. Ursprung, and E. R. Woods contributed to data collection for this work and reviewed the article.

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HUMAN PARTICIPANT PROTECTION

De-identified data were transferred from each program to Harvard T. H. Chan School of Public Health under data use agreements reviewed and approved by the institutional review boards of each institution involved, including Harvard.

REFERENCES

1. Centers for Disease Control and Prevention. Most recent asthma national data. Available at: http://www.cdc.gov/asthma/most_recent_data.htm. Accessed November 30, 2016.

2. Centers for Disease Control and Prevention. Most recent asthma state or territory data. Available at: http://www.cdc.gov/asthma/most_recent_data_states.htm. Accessed November 30, 2016.

3. Centers for Disease Control and Prevention. Uncontrolled asthma among persons with current asthma. Available at: http://www.cdc.gov/asthma/asthma_stats/uncontrolled_asthma.htm. Accessed November 30, 2016.

4. Braun-Fahrländer C, Riedler J, Herz U, et al. Environmental exposure to endotoxin and its relation to asthma in school-age children. *N Engl J Med*. 2002;347(12):869–877.

5. Huss K, Adkinson NF, Eggleston PA, Dawson C, Van Natta ML, Hamilton RG. House dust mite and cockroach exposure are strong risk factors for positive allergy skin test responses in the Childhood Asthma Management Program. *J Allergy Clin Immunol*. 2001;107(1):48–54.

6. National Asthma Education and Prevention Program. Expert Panel Report 3: Guidelines for the Diagnosis and Management of Asthma. Bethesda, MD: National Institutes of Health, National Heart, Lung, and Blood Institute; 2007.

7. Litonjua AA, Carey VJ, Weiss ST, Gold DR. Race, socioeconomic factors, and area of residence are associated with asthma prevalence. *Pediatr Pulmonol*. 1999;28(6):394–401.

8. Lieu TA, Lozano P, Finkelstein JA, et al. Racial/ethnic variation in asthma status and management practices among children in managed medicaid. *Pediatrics*. 2002;109(5):857–865.

9. Sommer SJ, Queenin LM, Nethersole S, et al. Children's Hospital Boston Community Asthma Initiative: partnerships and outcomes advance policy change. *Prog Community Health Partnersh*. 2011;5(3):327–335.

10. Sweet LL, Polivka BJ, Chaudry RV, Bouton P. The impact of an urban home-based intervention program on asthma outcomes in children. *Public Health Nurs*. 2014;31(3):243–252.

11. Parker EA, Israel BA, Robins TG, et al. Evaluation of community action against asthma: a community health worker intervention to improve children's asthma-related health by reducing household environmental triggers for asthma. *Health Educ Behav*. 2008;35(3):376–395.

12. Primomo J, Johnston S, DiBiase F, Nodolf J, Noren L. Evaluation of a community-based outreach worker program for children with asthma. *Public Health Nurs*. 2006;23(3):234–241.

13. Turyk M, Banda E, Chisum G, et al. A multifaceted community-based asthma intervention in Chicago: effects of trigger reduction and self-management education on asthma morbidity. *J Asthma*. 2013;50(7):729–736.

14. Krieger JW, Takaro TK, Song L, 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.

15. Woods E, Bhaumik U, Sommer S, et al. Community Asthma Initiative to improve health outcomes and reduce disparities among children with asthma. *MMWR Suppl*. 2016;65(1):11–20.

16. Woods ER, Bhaumik U, Sommer SJ, et al. Community Asthma Initiative: evaluation of a quality improvement program for comprehensive asthma care. *Pediatrics*. 2012;129(3):465–472.

17. Bhaumik U, Sommer SJ, Giller-Leinwohl J, Tsopelas L, Nethersole S, Woods ER. Boston Children's Hospital Community Asthma Initiative: five-year cost analyses of a home visiting program. *J Asthma*. 2017;54(2):134–142.

18. Asthma Regional Council. New England Asthma Innovations Collaborative (NEAIC). Health Resources in Action/Asthma Regional Council of New England (ARC). Available at: http://asthmaregionalcouncil.org/our-work/neaic. Accessed November 30, 2016.

19. Smith LA, Sandel MT, Sadof M, Zotter JM. Final Report: NIH Health Disparities Reducing Ethnic/Radial Asthma Disparities in Youth (READY) Study. Boston, MA: Massachusetts Department of Public Health; 2015.

20. Nathan RA, Sorkness CA, Kosinski M, et al. Development of the Asthma Control Test: a survey for assessing asthma control. *J Allergy Clin Immunol*. 2004;113(1):59–65.

21. Schatz M, Sorkness CA, Li JT, et al. Asthma Control Test: reliability, validity, and responsiveness in patients not previously followed by asthma specialists. *J Allergy Clin Immunol*. 2006;117(3):549–556.

22. Schatz M, Kosinski M, Yarlas AS, Hanlon J, Watson ME, Jhingran P. The minimally important difference of the Asthma Control Test. *J Allergy Clin Immunol*. 2009;124(4):719–723.e1.

23. Averbach AR, Lam D, Lam LP, Sharfstein J, Cohen B, Koh H. Smoking behaviours and attitudes among male restaurant workers in Boston's Chinatown: a pilot study. *Tob Control*. 2002;11(suppl 2):ii34–ii37.

24. Salari K, Burchard EG. Latino populations: a unique opportunity for epidemiological research of asthma. *Paediatr Perinat Epidemiol*. 2007;21(suppl 3):15–22.

25. *Profiles of Boston's Latinos*. Boston, MA: The Boston Planning & Development Agency; 2017.