

# Neighborhood differences in exposure and sensitization to cockroach, mouse, dust mite, cat, and dog allergens in New York City

Omar Olmedo, BS,<sup>a</sup> Inge F. Goldstein, DrPH,<sup>b</sup> Luis Acosta, MD,<sup>a</sup> Adnan Divjan,<sup>a</sup> Andrew G. Rundle, DrPH,<sup>b</sup> Ginger L. Chew, ScD,<sup>a</sup> Robert B. Mellins, MD,<sup>e</sup> Lori Hoepner, MPH,<sup>a,c</sup> Howard Andrews, PhD,<sup>c,d</sup> Sara Lopez-Pintado, PhD,<sup>d</sup> James W. Quinn, MA,<sup>g</sup> Frederica P. Perera, DrPH,<sup>a</sup> Rachel L. Miller, MD,<sup>a,e,f</sup> Judith S. Jacobson, DrPH,<sup>b</sup> and Matthew S. Perzanowski, PhD<sup>a</sup> *New York, NY*

**Background:** Asthma prevalence varies widely among neighborhoods within New York City. Exposure to mouse and cockroach allergens has been suggested as a cause.

**Objective:** To test the hypotheses that children living in high asthma prevalence neighborhoods (HAPNs) would have higher concentrations of cockroach and mouse allergens in their homes than children in low asthma prevalence neighborhoods (LAPNs), and that these exposures would be related to sensitization and asthma.

**Methods:** In the New York City Neighborhood Asthma and Allergy Study, a case-control study of asthma, children 7 to 8 years old from HAPNs (n = 120) and LAPNs (n = 119) were recruited through the same middle-income health insurance plan. Children were classified as asthma cases (n = 128) or controls without asthma (n = 111) on the basis of reported symptoms or medication use. Allergens were measured in bed dust.

**Results:** HAPN homes had higher Bla g 2 ( $P = .001$ ), Mus m 1 ( $P = .003$ ), and Fel d 1 ( $P = .003$ ) and lower Der f 1 ( $P = .001$ ) than LAPN homes. Sensitization to indoor allergens was associated with asthma, but relevant allergens differed between LAPNs and HAPNs. Sensitization to cockroach was more common among HAPN than LAPN children (23.7% vs 10.8%;  $P = .011$ ). Increasing allergen exposure was associated with

increased probability of sensitization (IgE) to cockroach ( $P < .001$ ), dust mite ( $P = .009$ ), and cat ( $P = .001$ ), but not mouse ( $P = .58$ ) or dog ( $P = .85$ ).

**Conclusion:** These findings further demonstrate the relevance of exposure and sensitization to cockroach and mouse in an urban community and suggest that cockroach allergen exposure could contribute to the higher asthma prevalence observed in some compared with other New York City neighborhoods. (*J Allergy Clin Immunol* 2011;■■■■:■■■■-■■■■.)

**Key words:** Asthma, urban, cockroach, mouse, dust mite, allergy

The prevalence of asthma varies among communities in the United States and is reported to be highest in low-income urban neighborhoods.<sup>1-3</sup> In New York City (NYC), asthma prevalence among children entering school varies by neighborhood from 3% to 19%.<sup>4</sup>

In inner-city communities, exposure to cockroach and mouse and sensitization to these pests have been associated with asthma morbidity. Most of these studies were conducted in high asthma prevalence neighborhoods in inner-city US communities.<sup>5-11</sup> The NYC Department of Health and Mental Hygiene (DOHMH) reported that cockroach and mouse sightings are more common in lower socioeconomic status (SES) neighborhoods, which also have a high pediatric asthma prevalence.<sup>12</sup> Therefore, sensitization and exposure to these pests may, in part, explain the differences in asthma prevalence and morbidity between neighborhoods in NYC. We are unaware of any studies that have directly examined this by measuring allergens and allergic sensitization in both the high and low asthma prevalence urban neighborhoods.

The NYC Neighborhood Asthma and Allergy Study (NAAS) is a case-control study that is recruiting children 7 to 8 years old with asthma (cases) and without asthma (controls) who live in high asthma prevalence neighborhoods (HAPNs) and low asthma prevalence neighborhoods (LAPNs) throughout NYC. To obtain a more homogeneous sociodemographic cohort, children were recruited through the same employer-based, middle-income health insurance plan. We hypothesized that despite being of similar SES, having similar access to health care, and living in the same city, children living in the HAPNs would have higher levels of cockroach and mouse allergens in their bed dust than children living in the LAPNs, and that these difference would be related to features of the neighborhood built and social environment.

From <sup>a</sup>the Department of Environmental Health Sciences, <sup>b</sup>the Department of Epidemiology, <sup>c</sup>the Data Coordinating Center, and <sup>d</sup>the Department of Biostatistics, Mailman School of Public Health, <sup>e</sup>the Department of Pediatrics, and <sup>f</sup>the Division of Pulmonary, Allergy, Critical Care Medicine, Department of Medicine, College of Physicians and Surgeons, and <sup>g</sup>the Institute for Social and Economic Research and Policy, Columbia University.

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Reprint requests: Matthew S. Perzanowski, PhD, Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, 60 Haven Avenue,

B-1, New York, NY 10032. E-mail: mp2217@columbia.edu.  
0091-6749/\$36.00

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**Abbreviations used**

DOHMH: Department of Health and Mental Hygiene  
 HAPN: High asthma prevalence neighborhood  
 HIP: Health Insurance Plan of New York  
 LAPN: Low asthma prevalence neighborhood  
 LOD: Limit of detection  
 NAAS: Neighborhood Asthma and Allergy Study  
 NYC: New York City  
 OR: Odds ratio  
 SES: Socioeconomic status

Further, we hypothesized that allergen exposure would be associated with sensitization and that sensitization would be related to asthma case status (Fig 1).

**METHODS****Study cohort**

The NYC NAAS is a case-control study of children with asthma. Parents of children 7 and 8 years old were recruited through the Health Insurance Plan of New York (HIP), a provider used primarily by a middle-income population. Neighborhoods were selected based on zip code level asthma prevalence among 5-year-old children as reported by the NYC DOHMH.<sup>4</sup> Asthma prevalence cutpoints for LAPNs and HAPNs were selected to yield an approximately equal number of eligible families in each neighborhood category. All NYC neighborhoods in the Bronx, Brooklyn, Queens, and Manhattan below (<9%) and above (>11%) these cutpoints were selected for recruitment.

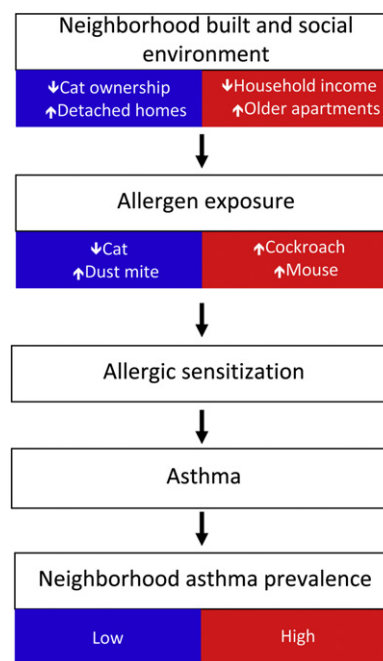
Each 3 months, all of the parents who (1) had HIP through an employer, (2) had a child who would turn 7 years old in the subsequent 3 months (8-year-olds were also recruited initially), and (3) resided in a selected zip code were contacted by HIP by mail, inviting them to participate in a brief screening questionnaire. With the initial recruitment between 2008 and 2009, potential participants were contacted by HIP by mail and telephone. Because of changes in research requirements at HIP in the summer of 2009, the recruitment procedure was modified to include contact by mail only. Families who were interested in participating in the study directly contacted the Columbia University research team. The demographics of those who did and did not participate in the study are described in Table 1 and in Table E1 and E2 in this article's Online Repository at [www.jacionline.org](http://www.jacionline.org).

**Screening questionnaire and home visit**

A brief telephone interview was administered to the parents, during which the child's eligibility was confirmed (age, insurance, and residence). The screening questionnaire also included ascertainment of demographic information on the child and administration of the International Study of Asthma and Allergy in Childhood questionnaire.<sup>13</sup> Medication use for asthma was ascertained by the question, "Is your child currently taking any medication to treat or prevent wheezing, cough or other breathing problems, rhinitis or allergies?" followed by a question about specific medications with a list of possibilities.<sup>14</sup> Homes of willing families were visited. During the visit, a detailed questionnaire on the health history of the child, environmental exposures, and socioeconomic and demographic information was administered.

**Asthma case definition**

Children were classified as having asthma on the basis of whether the parent reported at least 1 of the following for the child in the 12 months before administration of the questionnaire: (1) wheeze, (2) being woken at night by cough without having a cold, (3) wheeze with exercise, or (4) report of medication use for asthma. Children who did not meet 1 of these criteria were classified as controls. For sensitivity analyses, controls also were compared with children with frequent symptoms, defined as in the past 12 months having any wheeze-related symptom reported  $\geq 4$  times or sleep disturbed  $\geq 1$  time per



**FIG 1.** Hypothesized mechanism of association between features of neighborhood and asthma prevalence through allergen exposure.

week. Asthma cases with less frequent symptoms were excluded from these sensitivity analyses. The initial study design called for inviting all children with asthma and a matched number of randomly selected controls for a home visit. In practice, this recruitment method yielded an approximately equal number of children with and without asthma symptoms; therefore, all families were invited for the home visit.

**Allergen measurements in the home**

During the home visit, a dust sample was collected from the child's bed by vacuuming the fitted sheet on the upper half of the bed and both sides of the pillows using a vacuum cleaner and Dustream collector (Indoor Biotechnologies, Charlottesville, Va) for 3 minutes. The bed dust samples were extracted with PBS 0.05% Tween, pH 7.4, at a concentration of 50 mg/mL and stored at  $-20^{\circ}\text{C}$  until analysis. Der f 1, Fel d 1, Can f 1, and Mus m 1 were measured by multiplex bead immunoassays.<sup>15</sup> Bla g 2 was measured by ELISA (Indoor Biotechnologies).<sup>16</sup> All results are based on the universal allergen standard curve.<sup>17</sup> For results below the limit of detection (LOD), values of  $\frac{1}{2}$  LOD were used in analyses. LODs and coefficients of variance for duplicates are described in this article's Results (Table E3) in the Online Repository at [www.jacionline.org](http://www.jacionline.org). Four of the samples assayed by multiplex lacked a sufficient sample for Bla g 2 analyses. Allergen concentrations in this study were compared to those from other studies (see Table E4 in this article's Online Repository at [www.jacionline.org](http://www.jacionline.org)).

**Serum antibodies**

IgE against German cockroach, mouse urine proteins, *Dermatophagoides farinae*, cat dander, dog dander, common ragweed, mixed tree pollen (Phadia code Tx8), and mixed grass pollen (Phadia code Gx2) were measured in serum by ImmunoCAP (Phadia, Uppsala, Sweden). Children with specific IgE  $\geq 0.35$  IU/mL against any of the allergens tested were considered seroatopic. Sensitivity analyses were also conducted with the cutpoint of 1.0 IU/mL (see this article's Table E5 and Fig E1 in the Online Repository at [www.jacionline.org](http://www.jacionline.org)).<sup>18</sup>

**Local neighborhood level variables**

Children's home addresses were geocoded and linked to a comprehensive geospatial demographic database described previously.<sup>19</sup> The median

TABLE I. Study demographics

	LAPN* (n = 119)	HAPN* (n = 120)	P value
Case: control (n)	61:58	67:53	—
Male (%)	58.0	50.0	.22
Race (%)†			<.001
White	20.2	7.5	
Black	36.1	53.3	
Asian	21.0	1.7	
Other/mixed	17.6	32.5	
Hispanic ethnicity (%)‡	23.5	47.5	.001
Household income <\$25K (%)	8.4	11.7	.40
Household family income (median)	\$60-70K	\$45-50K	.001
Household incomes for surrounding 500 m (median)§	\$42K	\$21K	<.001
People in home per bedroom (median)	1.8	2.0	.14
Maternal education (%)			.083
Not completed high school	7.6	10.1	
Bachelor's degree or higher	49.6	35.3	
Paternal education (%)			.001
Not completed high school	6.0	8.9	
Bachelor's degree or higher	44.0	21.4	
Housing type (%)			<.001
Single family home	32.8	5.0	
Multifamily home	36.1	14.2	
Apartment building	31.1	80.8	
Age of home (median)	1939	1934	.58
Cat in home (%)	6.7	17.5	.011
Lived in the same neighborhood for ≥7 years (%)	68.7	70.1	.85

\*Children living in LAPNs and HAPNs.

†There were 6 (5%) children in the LAPNs and 6 (5%) in the HAPNs that did not have a report for race.

‡There were 4 (3.4%) children in the LAPNs and 7 (5.8%) in HAPNs that did not have a report for Hispanic ethnicity.

§Home address-linked, census-based variable of the median income of the household in the surrounding radial 500 m was available for a subset (n = 208) of the children.

household income in the surrounding 500-m radius was determined for each home. Neighborhood asthma prevalence was based on previously described data from NYC DOHMH.<sup>4</sup>

## Statistics

Because both IgE and allergen concentrations were log-normally distributed, logarithmically transformed values were used in analyses. Geometric means with 95% CIs are reported. To adjust for potential confounders and covariates, the associations between allergic sensitization and asthma case status and allergen levels and sensitization were obtained by using logistic regression. Interactions between allergic sensitization and neighborhood type were tested on a multiplicative scale. Linear regression models were used to predict variation in allergen exposure in the home with variables related to home characteristics, family behaviors, and local neighborhood income. Variables were entered stepwise and removed from the model if they did not alter the  $\beta$  for the association between neighborhood asthma prevalence and allergen level or the overall regression coefficient by >10%. Data were analyzed in SPSS version 17 (SPSS, Chicago, Ill).

## RESULTS

A total of 403 parents completed the screening questionnaire, and of those, 248 had a home visit. There were no significant differences in the demographics of the families with and without a home visit (see Table E1). Among those with a home visit, 9

children were missing allergen data or data used to define case status, leaving 239 children for allergen exposure analyses. Among these, 225 donated serum for IgE analyses. Children recruited by the initial method that included telephone contact compared with those recruited only by postal invitation were similar in all demographics except race and household income below \$25,000/y (see Table E2).

## Study population

There were approximately equal numbers of children from HAPNs (n = 119) and LAPNs (n = 120; Fig 2). Compared with children living in the LAPNs, those in the HAPNs were more likely to be of black race or Hispanic ethnicity and to live in apartment buildings (Table I). Reporting a household income below the poverty line was rare. Among the 128 cases, 54 were classified as having frequent symptoms.

## Neighborhood features, asthma prevalence, and bed dust allergens

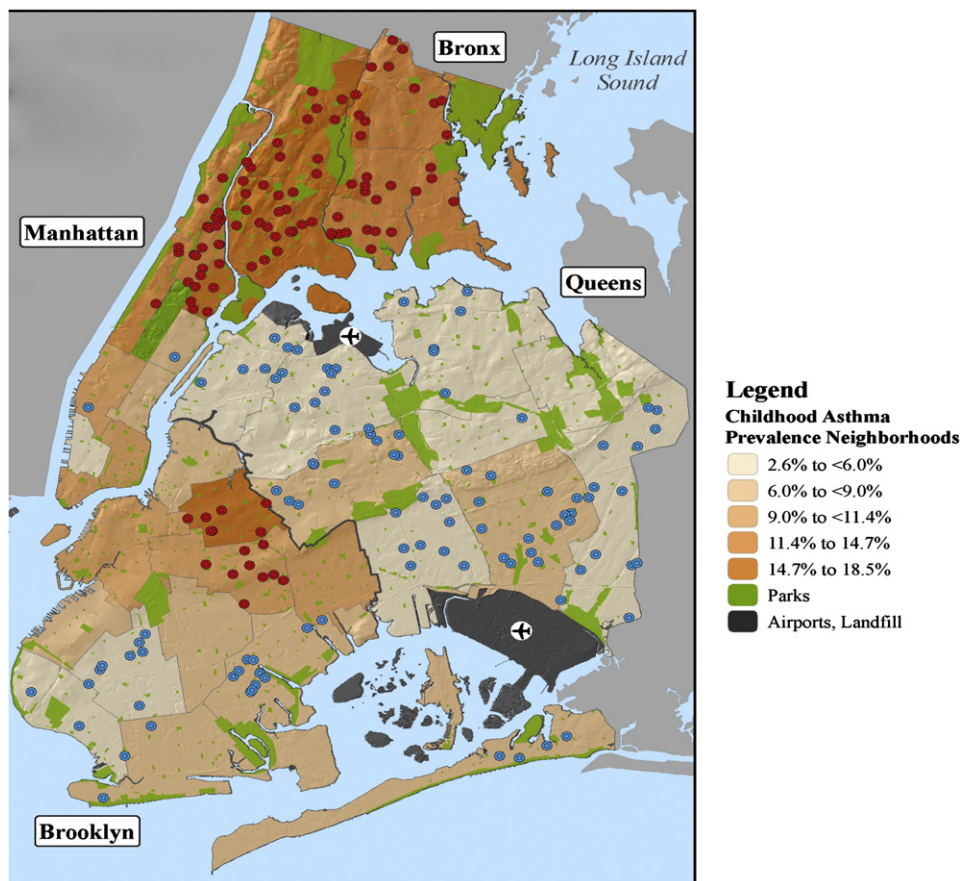
Compared with LAPN homes, HAPN homes had *higher* mean Bla g 2 (22 ng/g [19-25] vs 37 ng/g [28-47];  $P = .001$ ), Mus m 1 (41 ng/g [30-56] vs 93 ng/g [61-142];  $P = .003$ ), and Fel d 1 (30 ng/g [24-39] vs 56 ng/g [41-76];  $P = .003$ ); *lower* Der f 1 (10 ng/g [7.7-14] vs 5.3 ng/g [4.2-6.8];  $P = .001$ ); and *similar* Can f 1 (84 ng/g [57-124] vs 99 ng/g [70-141];  $P = .54$ ) concentrations in bed dust (Fig 3). The difference in cat allergen between neighborhoods was driven by the greater frequency of cat ownership in HAPN versus LAPN homes (17.5% vs 6.7%;  $P = .011$ ) that was not observed for dog ownership (12.5% vs 15.1%;  $P = .56$ ).

In multivariable models (Table II), Bla g 2 concentrations were higher among homes reporting cat ownership and inversely associated with local neighborhood income. Mus m 1 was higher for children who ate in their bedroom, lower for homes on  $\geq 8$ th floor, and inversely associated with local neighborhood income. Der f 1 concentrations were higher in detached homes and homes with cats, lower in beds of children whose parent reported that they had ever encased bedding because of their child's asthma or allergy, and inversely associated with the age of the building. Fel d 1 was associated only with pet ownership (data not shown).

## Allergic sensitization and asthma

Sensitization to cockroach allergen was more common among children (cases and controls) living in the HAPNs than LAPNs (23.7% vs 10.8%;  $P = .011$ ). There were no significant differences by neighborhood in prevalence of sensitization to any of the other individual allergens, and overall sensitization to any allergen was equally common among children living in LAPNs and HAPNs (53.2% vs 50.0%, respectively;  $P = .64$ ).

Sensitization to inhalant allergens was more common among children with asthma than controls for children living in both the LAPNs ( $P < .001$ ) and the HAPNs ( $P = .038$ ; Table III). Although the adjusted odds ratios (ORs) for case status with sensitization were higher for cockroach, ragweed, and tree among HAPN versus LAPN children and vice versa for mouse allergen, the effect modification by neighborhood was statistically significant only for ragweed sensitization (Table III;  $P_{\text{interaction}} = .009$ ). When



**FIG 2.** Location of study participants. Each dot represents a study subject's home and is color-coded according to whether the subject has been classified as living in a LAPN (blue) or a HAPN (red). Neighborhoods are color-coded according to the legend by NYC DOHMH-reported asthma prevalence among 5-year-old children in 2000.

children with frequent symptoms (defined in Methods) were compared with controls, the ORs with cockroach, ragweed, and tree sensitization was higher for HAPN versus LAPN children, and the opposite pattern was observed for mouse and dust mite (data not shown). However, only the interaction term for ragweed approached statistical significance ( $P = .055$ ).

### Allergen exposure and sensitization

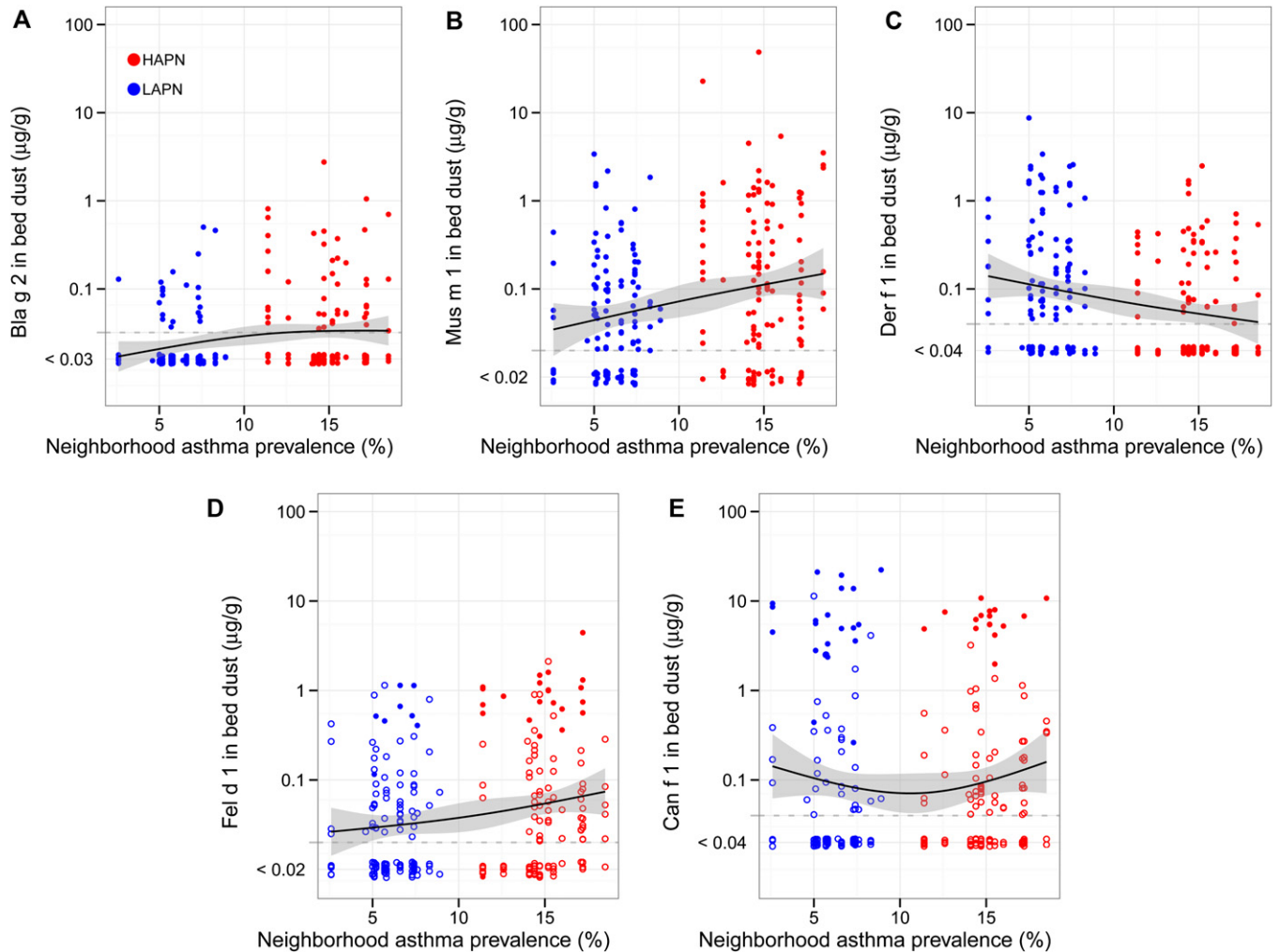
There was a significant association between bed dust allergen concentrations and sensitization for cockroach, dust mite, and cat, but not mouse or dog allergens (Fig 4). These associations held with adjustment for race, Hispanic ethnicity, sex, LAPN/HAPN, case/control, and maternal asthma (cockroach, OR, 1.9 [1.4-2.6];  $P < .001$ ; dust mite, OR, 1.3 [1.07-1.63];  $P = .009$ ; cat, OR, 1.43 [1.16-1.75];  $P = .001$ ). Among children who had ever lived with a cat (21%), sensitization to cat was more common than for those who had not (40.4% vs 18.6%;  $P = .002$ ). Among children who had ever lived with a dog (14%), the prevalence of sensitization to dog was similar to that of children who had not (18.8% vs 20.2%;  $P = .85$ ).

Mean cockroach, mouse, dust mite, cat, or dog concentrations were not significantly different for children with or without a case definition of asthma or frequent symptoms (data not shown). Neither current nor ever ownership of a cat or

dog were associated with case or frequent symptom status ( $P$  values = .16-.78). We did not have a sufficient sample size to examine the associations between allergen exposure and symptoms among the children with asthma and sensitization to cockroach ( $n = 29$ ), mouse ( $n = 18$ ), dust mite ( $n = 36$ ), cat ( $n = 34$ ), or dog ( $n = 33$ ).

### DISCUSSION

Among a middle-income population of children 7 to 8 years old with and without asthma living throughout neighborhoods in NYC with large variations in asthma prevalence, mean cockroach, mouse, and cat allergen concentrations were higher and dust mite allergen concentrations were lower in the bed dust from the HAPN compared with LAPN homes. These associations between neighborhood asthma prevalence and allergen concentrations were partially explained by home characteristics, living habits, and local neighborhood economic variables. Sensitization to indoor allergens was associated with asthma in general, but relevant allergens differed between LAPNs and HAPNs. Exposures to cockroach, dust mite, and cat allergens were significantly associated with sensitization. These findings further demonstrate the relevance of exposure and sensitization to cockroach, mouse, dust mite, and cat in an urban community and suggest that cockroach allergen exposure could contribute



**FIG 3.** Cockroach (A), mouse (B), dust mite (C), cat (D), and dog (E) allergen in the child's bed dust by neighborhood asthma prevalence. Lines represent natural spline linear models smoothed with 3 degrees of freedom with 95% CIs (gray). For D and E, full circles represent homes with cat or dogs, respectively, and empty circles represent those without.

to the higher asthma prevalence observed in some NYC neighborhoods.

Although many studies have focused on environmental exposures among inner-city subjects with asthma,<sup>9</sup> to our knowledge, none have included a comprehensive study of environmental exposures in geographically adjacent low asthma prevalence communities. In NYC and other US cities, asthma prevalence is higher in communities with lower SES and a higher proportion of racial and ethnic minorities.<sup>3,4,20</sup> We designed the NYC NAAS to minimize heterogeneity in SES, race, and ethnicity by recruiting through a middle-income health insurance plan. Although families represented a range of incomes, they were primary of middle income, living among higher (LAPN) and lower (HAPN) socioeconomic communities. Also, although there were more black subjects among our HAPN participants, one third of the children in the LAPNs were black. Despite living in or near what would be considered inner-city neighborhoods, HAPN families in our cohort differed in demographics from previous inner-city cohort studies. For example, mothers in our HAPNs compared with the National Cooperative Inner City

Asthma study populations were more likely to have a household income  $\geq$ \$30,000 (73% vs 22%), be married (55% vs 24%) and have a high school degree (90% vs 66%).<sup>21</sup>

Although the relationships between allergen levels and housing and household demographics have been examined in the United States on a national level, an advantage to focusing on a single city is decreasing the likelihood of confounding by regional differences (eg, building types, weather). For example, the National Survey of Lead and Allergens in the Home reported that homes in high-rise apartments had higher mouse allergen, but within NYC, we observed significantly lower mouse allergens in homes on the 8th floor or higher, which we also previously observed in a low-income HAPN cohort.<sup>22,23</sup> The National Survey of Lead and Allergens in the Home also reported that mouse and cockroach levels were higher in low-income than in higher-income homes.<sup>24,25</sup> In this NYC study of middle-income families, however, a child's neighborhood income was more important in predicting the likelihood of exposure to pests in the home than family income. It is important to point out that the allergen analyses were conducted by using the new allergen standards, and thus, direct

**TABLE II.** Association between domestic environmental exposures and neighborhood asthma prevalence in multivariable† regression models (n = 189)

Independent variable	Bla g 2‡	Mus m 1	Der f 1
Neighborhood asthma prevalence§	$\beta = -0.007$ (-0.058 to 0.044)	$\beta = 0.061$ (-0.025 to 0.15)	$\beta = -0.051$ (-0.11 to 0.008)
Age of building	$\beta < 0.001$ (-0.007 to 0.007)	—†	$\beta = -0.008$ (-0.015 to 0.0001)
Home is detached	$\beta = 0.19$ (-0.34 to 0.72)	$\beta = 0.76$ (-0.13 to 1.6)	$\beta = 1.0$ (0.42 to 1.64)**
Median household income (500 m) in \$10K	$\beta = -0.024$ (-0.043 to -0.006)*	$\beta = -0.047$ (-0.078 to -0.016)**	$\beta = 0.005$ (-0.016 to 0.027)
Home is on 8th or higher floor	—	$\beta = -1.2$ (-2.06 to -0.30)**	—
Number of people per bedroom	—	$\beta = 0.30$ (-0.037 to 0.64)	—
Cat in home	$\beta = 0.59$ (0.036 to 1.2)*	—	$\beta = 2.1$ (1.4 to 2.7)***
Ever changed or encased mattress or pillow because of child's asthma or allergy symptoms	—	—	$\beta = -0.74$ (-1.4 to -0.065)*
Child eats food in bedroom	$\beta = 0.11$ (-0.25 to 0.46)	$\beta = 0.94$ (0.35 to 1.53)**	—
Overall model	$R = 0.39$ ; $P = .002$	$R = 0.48$ ; $P < .001$	$R = 0.57$ ; $P < .001$

\* $P < .05$ ; \*\* $P < .01$ ; \*\*\* $P < .001$ .

†Multivariable regression models were built and variables were removed stepwise if they did not alter the  $\beta$  for the association between neighborhood asthma prevalence and allergen level or the overall regression coefficient by 10% or more. The variables case/control status, race of child, Hispanic ethnicity, and reported household family income were used in all models, although none of these was statistically significant in any of the models.  $\beta$  Values with 95% CIs are reported. Dashes indicate variables not included in the final model.

‡Allergen levels were log-transformed in regression models.

§School-based prevalence of asthma among 5-year-old children for the child's United Hospital Fund Neighborhood (several zip codes).

||Geographic Information System census-based variable of the median income of the household in the surrounding radian 500 m.

comparisons to previously published concentrations should be performed after applying published correction factors.<sup>17</sup> Bla g 2 concentrations were similar to those reported from 2 previous studies in Northeastern US cities (see Results and Table E4 in the Online Repository).<sup>23,26</sup> Fel d 1 allergen concentrations were lower than those reported for the United States in general but similar to those reported in US inner-city homes.<sup>27,28</sup> Mus m 1 concentrations were similar to those reported from inner-city homes.<sup>28</sup>

Higher concentrations of dust mite allergens in the LAPN compared with HAPN homes also were observed. This finding is not particularly surprising because it has been reported previously that apartment buildings in the Northeast are overheated in the winter, leading to a dryer environment less conducive to dust mites.<sup>29</sup> A principal difference between the HAPN and LAPN homes is housing type, with apartments much more common in the HAPNs and detached homes more common in the LAPNs. Dust mite allergen concentrations were significantly higher among single-family and newer homes, which presumably are less likely to be overheated.

In the study sample overall, sensitizations to cockroach, mouse, dust mite, and cat were important risks for being classified as an asthma case, reinforcing the importance of examining domestic exposure to these allergens. A novel finding was that ragweed sensitization appeared to be a greater risk for asthma in the LAPNs than in the HAPNs. This study is not a prevalence study, so although we have approximately equal numbers of subjects with asthma from the HAPNs and LAPNs, they do not represent an equal proportion of the population in their neighborhoods. As such, the HAPN subjects with asthma may be a more heterogeneous population of subjects with asthma with and without allergic triggers, whereas the LAPN children may be a more homogeneous allergy-triggered asthma population. Also, given that the LAPN children live in less densely populated environments, their exposure to ragweed may be greater.

A significant association between allergen exposure and sensitization for cockroach and dust mite was observed; however, we did

not observe an association for mouse. The study might have been underpowered to detect such an association given the low prevalence of sensitization to mouse (11%). However, mouse allergens typically travel on smaller particles that are more likely to become and remain airborne than the larger particles that carry dust mite and cockroach allergens. This may contribute to higher exposure to mouse than dust mite and cockroach allergens outside the home (eg, subway stations, schools). We have previously observed that mouse allergen was detectable in 81% of air samples in schools, whereas cockroach was detectable in only 22% of samples.<sup>30</sup>

As we have reported from a study of low-income children living in HAPNs previously, children in homes with cats and higher levels of cat allergen were more likely to be sensitized to cats.<sup>31</sup> There has been much debate in the literature about the association between cats in the home and development of allergic disease with increased, decreased, and no associations reported.<sup>32–36</sup> Urban NYC children seem to fall into an exposure paradigm similar to those in other communities with relatively moderate or low cat ownership.<sup>31,34</sup> In these communities, passively transferred cat allergens are less common because of lower community cat ownership. Thus, at least early in childhood, having a cat at home may be necessary for many atopic individuals to be exposed to sufficient allergen to become allergic. However, we found no association between cat ownership or allergen levels and asthma status, further suggesting a complicated relationship between exposure to cats and development of allergic disease.

There are several limitations of our study. Although there did not appear to be a bias in home visits among those who completed the telephone survey (Table E1), there was a bias in who chose to participate in the telephone survey (on the basis of the similar number of cases and controls, whereas controls should have been more common in the target population). A wide range of variables to control for potential confounding was assessed, but there is a possibility of unrecognized confounders. The symptom and medication-based definition we have used is more sensitive and less specific, and thus may result in children without asthma being classified as having asthma.

**TABLE III.** Association between allergen-specific sensitization and case versus control with stratification by neighborhood asthma prevalence

Sensitization†	Overall LAPN and HAPN (n = 225)		LAPN (n = 111)		HAPN (n = 114)		<i>P</i> <sub>interaction</sub> between LAPN and HAPNs
	(%)	Adjusted OR (95% CI)‡	(%)	Adjusted OR (95% CI)	(%)	Adjusted OR (95% CI)	
Cockroach							
Nonasthma	9.6		3.8		15.7		
Asthma	24.0	2.85 (1.23-6.59)*	17.2	7.34 (1.28-42.0)*	30.2	2.34 (0.84-6.50)	.27
Mouse							
Nonasthma	5.8		7.5		3.9		
Asthma	14.9	2.46 (0.91-6.67)	10.3	1.39 (0.35-5.59)	19.0	5.64 (1.08-29.4)*	.29
Dust mite							
Nonasthma	15.4		18.9		11.8		
Asthma	29.8	2.55 (1.27-5.13)**	34.4	2.66 (1.00-7.07)	25.4	3.11 (1.03-9.37)*	.91
Cat							
Nonasthma	17.8		13.5		21.6		
Asthma	28.1	1.67 (0.83-3.37)	27.6	2.48 (0.79-7.83)	28.6	1.47 (0.55-3.96)	.34
Dog							
Nonasthma	11.5		9.4		13.7		
Asthma	27.3	2.78 (1.29-5.99)**	25.9	3.14 (0.99-10.0)	28.6	2.91 (0.98-8.65)	.61
Any indoor							
Nonasthma	29.8		30.2		29.4		
Asthma	52.1	2.44 (1.37-4.34)**	55.2	3.12 (1.31-7.44)*	49.2	2.39 (1.01-5.65)*	.70
Ragweed							
Nonasthma	13.5		7.5		19.6		
Asthma	27.3	2.15 (1.04-4.44)*	34.5	6.08 (1.80-20.5)**	20.6	0.80 (0.29-2.22)	.009
Tree							
Nonasthma	16.5		13.5		19.6		
Asthma	38.0	3.14 (1.60-6.18)**	43.1	4.77 (1.67-13.6)**	33.3	2.37 (0.89-6.28)	.23
Grass							
Nonasthma	12.5		13.2		11.8		
Asthma	19.0	1.52 (0.71-3.26)	24.1	1.87 (0.65-5.38)	14.3	1.04 (0.31-3.49)	.40
Any outdoor							
Nonasthma	21.2		17.0		25.5		
Asthma	41.3	2.59 (1.37-4.86)**	43.1	3.47 (1.30-9.29)*	39.7	2.03 (0.83-4.97)	.30
Any allergen							
Nonasthma	36.5		34.0		39.2		
Asthma	64.5	3.14 (1.76-5.62)***	70.7	5.36 (2.12-13.5)***	57.7	2.31 (1.02-5.21)*	.14

\**P* < .05; \*\**P* < .01; \*\*\**P* < .001.

†Children were considered sensitized to an allergen if they had &gt;0.35 IU/mL IgE against that allergen.

‡ORs were adjusted for race, Hispanic ethnicity, sex, maternal asthma, and cockroach, mouse, dust mite, and cat allergen concentrations in bed dust in logistic regression.

§Effect modification by neighborhood asthma prevalence was tested by using a multiplicative interaction term of allergen sensitization by neighborhood asthma prevalence group in logistic regression models.

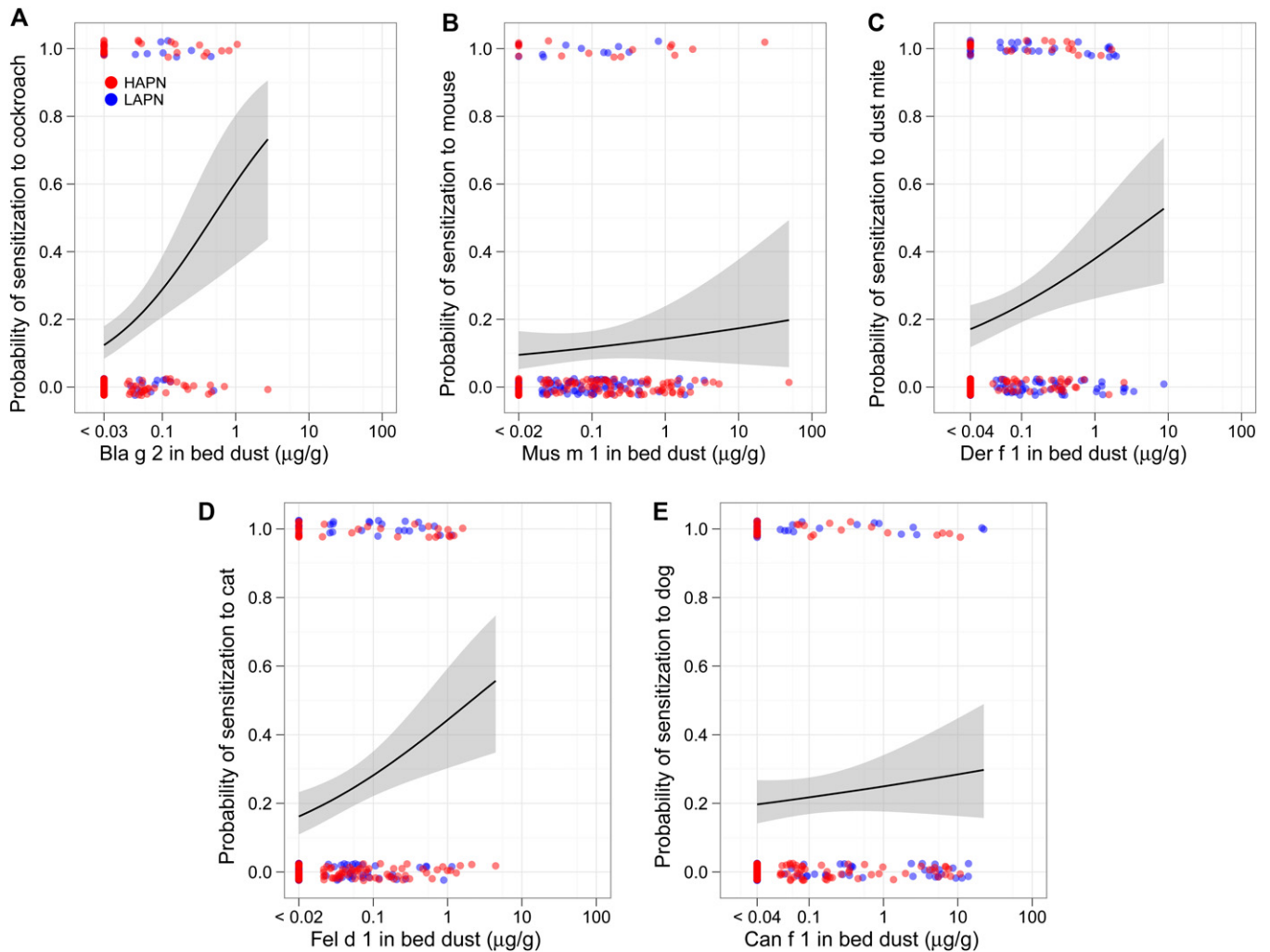
However, sensitivity analyses using the more specific definition based on frequent symptoms yielded similar results. Lower levels of IgE, such as those used in this study, may be transient in early childhood.<sup>37</sup> However, sensitivity analyses using the IgE cutpoint of 1.0 IU/mL, which Matricardi et al<sup>18</sup> found to be less subject to transience in children between the ages of 7 and 10 years, yielded similar results to those using the 0.35 IU/mL cutpoint (Fig E1, Table E5).

With this unique study cohort, significant differences in allergen exposure in homes throughout NYC have been demonstrated: (1) cockroach allergen was higher in the HAPN homes, (2) cockroach sensitization was higher among children living in the HAPNs, (3) cockroach allergen exposure was associated with sensitization, and (4) cockroach sensitization was associated with increased risk for asthma. These findings combined point to

cockroach allergen exposure potentially leading to a higher prevalence of asthma in some urban neighborhoods.

This project would not have been possible without our collaborators at HIP. Beatriz Jaramillo, DrPH, was instrumental in the design and initial implementation of the study, and Michael Byrne, MA, has ensured the continued success of the recruitment for the study. We thank the NAAS field team for their hard work. We thank Stephanie Soucier for artistic design of recruitment material. We also thank the families who have participated in the study.

**Clinical implications: Sensitizations to cockroach, mouse, cat, and dust mite allergens are important predictors of asthma morbidity among children in the urban Northeast, but exposures may vary by neighborhood within a city.**



**FIG 4.** Probability of sensitization to cockroach (A), mouse (B), dust mite (C), cat (D), and dog (E) allergens with exposure to the relevant major allergen. Points represent allergen concentration in the bed dust on the x-axis and the absence (0) or presence (1) of IgE  $\geq 0.35$  IU/mL to the relevant allergen on the y-axis. Lines represent logistic regression models with 95% CIs (gray).

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## RESULTS

### Allergen assay LODs and coefficients of variance

Multiple dilutions of each sample were assayed for each allergen, and the means of the measurable results were calculated. To calculate the coefficient of variance (CV) for the allergen assays, the first 46 samples had multiplex and ELISA assays repeated on a different day. Because the allergen data are generally log-normally distributed and were treated as such throughout the analyses, CVs (SD divided by mean) for each assay were calculated on the basis of the log-transformed results. CVs and LODs are reported in Table E3.

### Comparison of allergen concentrations with those reported from other US populations

Median allergen concentrations from this study were compared with those reported from the US National Survey of Lead and Allergens in Housing and the US National Inner-City asthma study in Table E4.<sup>E1-E5</sup> To compare our results that were computed on the basis of the Universal Allergen Standard with those using previous allergen standards, published conversion factors were used (see Table E4 legend).<sup>E6</sup> Neither of these studies reported Bla g 2 concentrations (Bla g 1 concentrations were reported). In a study of patients with asthma and controls in Wilmington, Del, Gelber et al<sup>E7</sup> reported that 18 of 184 (ie, 9.8%) bed samples had greater than 2 U Bla g 2/g dust (equivalent to 136 ng Bla g 2/g dust using the Universal Allergen Standard). Among NYC women living in inner-city communities who were enrolled in a birth cohort study, we previously published Bla g 2 concentrations measured in their bed dust. Forty percent had greater than 2 U Bla g 2/g dust.<sup>E8</sup> Among the NAAS children, 23% of the bed samples had at least this concentration of Bla g 2.

### Sensitivity analyses with >1.0 IU/mL IgE cutpoint

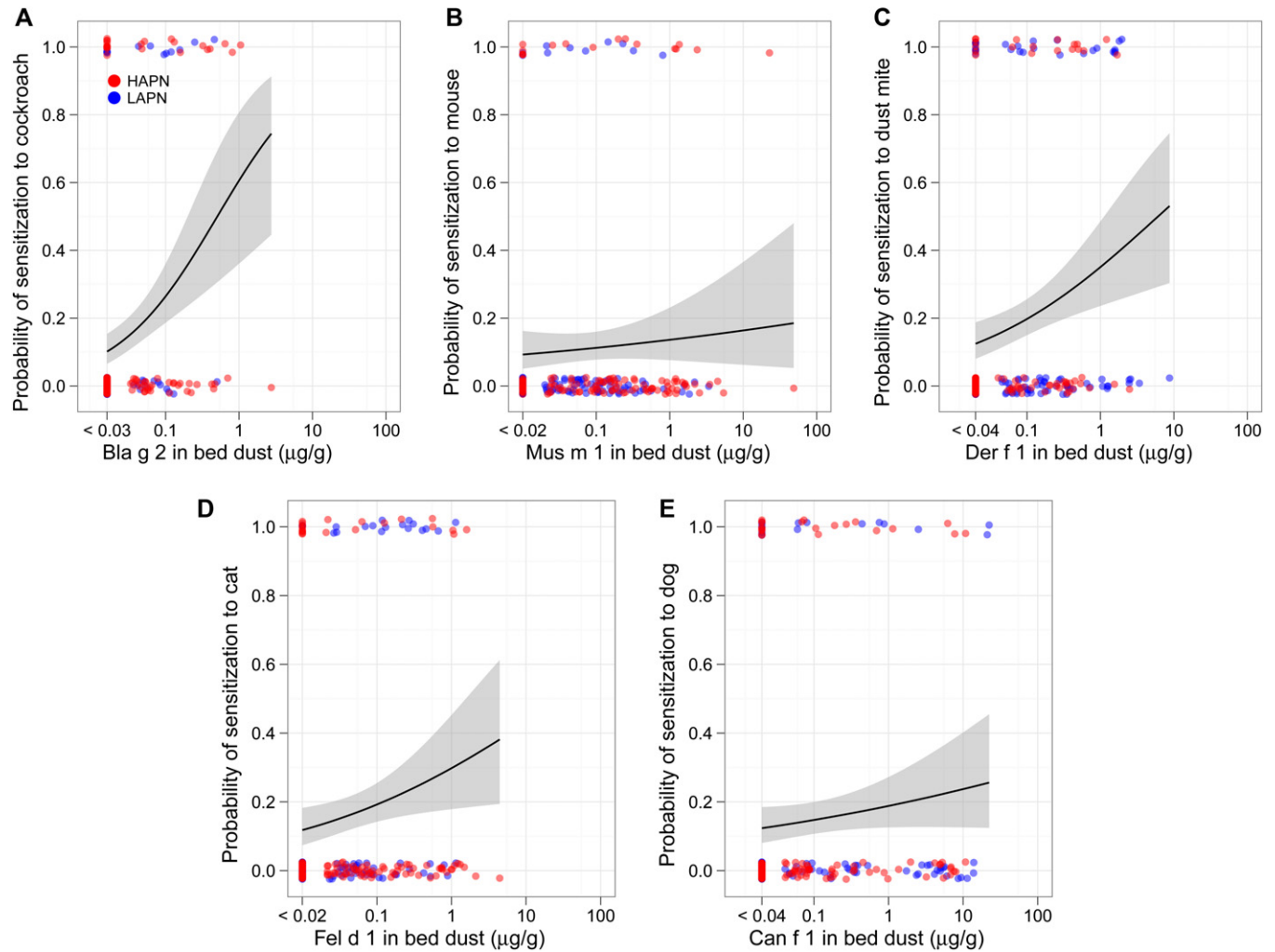
Similar to the analyses with the lower cutpoint ( $\geq 0.35$  IU/mL), children in the HAPNs compared with LAPNs had a higher prevalence of IgE  $\geq 1.0$  IU/mL to cockroach, although the difference was not statistically significant (19.3% vs 10.8%;  $P = .076$ ). The prevalence of sensitization to any of the other allergens as judged by the  $\geq 1.0$  IU/mL cutpoint was not statistically significantly different between children in the HAPNs and LAPNs (all  $P$  values  $> .1$ ). Overall, having IgE  $\geq 1.0$  IU/mL to at least 1 allergen was equally common among HAPNs (36.0%) and LAPNs (42.3%;  $P = .33$ ) children.

Associations between case status and sensitization using the 1.0 IU/mL cutpoint were observed similar to those observed by using the 0.35 IU/mL cutpoint (Table E5). Several of the associations were slightly stronger. Although the magnitudes of the estimated OR were similar using the 1.0 cut-point to those when the 0.35 cut-point was used, dust mite among the children in the LAPN and dog among the children in the HAPN were statistically significant ( $P < .05$ ) using the higher, but not lower cut point. There were only minimal increases in the magnitudes of the estimated OR between the 0.35 and 1.0 cutpoints. Ragweed sensitization remained only a risk for asthma case among the LAPN and not HAPN children, with a statistically significant interaction term (Table E5).

The associations between bed dust allergen concentrations and sensitization to the relevant allergen were similar using the higher cutpoint (Fig E1). These associations remained unchanged after adjustment for race, Hispanic ethnicity, sex, LAPN/HAPN, case/control, and maternal asthma (cockroach, OR, 2.09 [95% CI, 1.51-2.90],  $P < .001$ ; mouse, OR, 1.02 [95% CI, 0.82-1.25],  $P = .88$ ; dust mite, OR, 1.43 [95% CI, 1.14-1.78],  $P = .002$ ; cat, OR, 1.35 [95% CI, 1.08-1.69],  $P = .008$ ; dog, OR, 1.10 [95% CI, 0.92-1.32],  $P = .29$ ).

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**FIG E1.** Probability of sensitization to cockroach (A), mouse (B), dust mite (C), cat (D), and dog (E) allergens with exposure to the relevant major allergen. Points represent allergen concentration in the bed dust on the *x*-axis and the absence (0) or presence (1) of IgE  $\geq 1.0$  IU/mL to the relevant allergen on the *y*-axis. Lines represent logistic regression models with 95% CIs (gray).

**TABLE E1.** Demographics of those families who had a home visit and those who did not\*

Demographics	Home visit and serum (n = 230)	Home visit, no serum (n = 18)	No home visit, no serum (n = 155)
HAPN (%)†	51.3	44.4	44.5
Case selection related symptoms (%)‡			
Wheeze	31.1	44.4	33.5
Wheeze with exercise	19.7	27.8	15.5
Woken at night by cough without having a cold	40.6	44.4	38.1
Use of medications for asthma	34.9	50.0	36.1
Male (%)	54.8	50.0	51.0
Race (%)§			
White	13.9	27.8	14.8
Black	45.7	27.8	48.4
Asian	11.3	5.6	12.9
Other/mixed	24.3	33.3	20.0
Hispanic ethnicity (%)	37.1	33.3	25.8
Household income <\$25K (%)	10.4	11.1	11.6
Household income (median reported range)	\$50-60K	\$50-60K	\$50-60K
Household incomes for surrounding 500 m (median)¶	\$33K	\$41K	\$35K
Maternal asthma (%)#	20.5	50.0	21.3
Paternal asthma (%)#	17.2	11.8	14.3

\* $P < .05$  from children with screening, home visit, and serum (there were no significant differences between these groups).

†Children not in the HAPNs were in the LAPNs.

‡Symptoms reported in the past 12 months on the screening questionnaire.

§There were 11 (4.8%), 1 (5.6%), and 6 (3.9%) children who did not have a race reported in the groups from left to right.

||There were 8 (3.5%), 2 (11%), and 6 (3.9%) children who did not have a report for Hispanic ethnicity in the groups from left to right.

¶Geographic Information System census-based variable of the median income of the household in the surrounding radius 500 m. This was available on a subset of the children with a home visit with (n = 194) and without (n = 15) serum and children without a home visit (n = 118).

#There were 2 (0.9%), 0, and 3 children without a report for maternal asthma and (1.9%) 6 (2.6%), 0, 8 (5.2%) without a report for paternal asthma in the groups from left to right.

**TABLE E2.** Demographics of those families recruited by the initial method that included telephone contact and those recruited by the method that only used postal invitations

Demographics	Initial recruitment including telephone contact (n = 108)	Recruitment by postal invitation only (n = 131)
HAPN (%)	46.3	53.8
Asthma case (%)†	50.0	56.5
Frequent symptoms (%)	22.2	22.9
Atopic to any allergen tested (%)	49.5	53.2
Male (%)	51.9	55.7
Race (%)		
White	14.8	13.0
Black	35.2	52.7*
Asian	15.7	7.6*
Other/mixed	26.9	23.7
Hispanic ethnicity (%)	35.2	35.9
Household income <\$25K (%)	14.8	6.1*
Household income (median reported range)	\$60-70K	\$50-60K
Household incomes for surrounding 500 m (median)	\$35.9K	\$30.4K
Maternal asthma (%)	25.0	16.8
Paternal asthma (%)	18.1	14.6

\**P* < .05 between recruitment methods.†Children with specific IgE  $\geq 0.35$  IU/mL to any of the allergens tested. There were 99 and 126 children with IgE data available among the children with and without telephone contact, respectively.

**TABLE E3.** LODs and CVs for the allergen assays

Allergen	LOD ( $\mu\text{g/g}$ )	CV (%)†
Bla g 2	0.03	4.8
Mus m 1	0.002*	15.5
Der p 1	0.04	1.6
Der f 1	0.04	14.0
Fel d 1	0.02	6.8
Can f 1	0.04	2.4

\*So that the plots for the other allergens would be comparable in Figs 3, 4, and E1, Mus m 1 was plotted with a LOD of 0.02  $\mu\text{g/g}$ . Mus m 1 results throughout were similar when either 0.02 or 0.002 was used as the LOD.

†CV based on assays repeated for the first 46 samples on 2 separate days.

**TABLE E4.** Comparison of median allergen levels in NAAS to those reported from other studies

Allergen	US National Survey of Allergens*		US Inner-City Asthma Study†	
	Median‡	% NAAS samples above median§	Median‡	% NAAS samples above median§
Mus m 1 (µg/g)	0.25	25.5	0.04	58.2
Der p 1 (µg/g)	—¶	—	0.03	<90.0
Der f 1 (µg/g)	—	—	0.10	<47.7
Der p 1 + Der f 1 (µg/g)	1.53	43.9	—	—
Fel d 1 (µg/g)	1.3	13.4	0.09	50.6
Can f 1 (µg/g)	1.8	23.4	0.54	32.1

\*Reported from the National Survey of Lead and Allergens in the Home.<sup>E1-E3</sup>

†Reported from the most recent US Inner-City Asthma Study.<sup>E4,E5</sup>

‡Medians from the 2 studies were used for comparison with our study in this table instead of geometric means because the studies had different assay LODs, which will affect the geometric mean but not median, unless more than ½ of the samples are below the LOD.

§To convert our medians to those published previously (and shown in table), our medians were multiplied by published conversion factors: Mus m 1 (1.10), Der p 1 (1.70), Der f 1 (12.66), Fel d 1 (3.40), and Can f 1 (5.81). Bla g 2 results were not reported from either study.<sup>E6</sup>

||Both Der p 1 and Der f 1 LODs were higher than the medians reported from the US Inner-city Asthma Study. Percentages represent the number of sample below the LOD for Der p 1 and Der f 1 (equivalent to 0.068 µg/g and 0.51 µg/g of the allergen standards used in the Inner-city Asthma Study, respectively).

¶Only the sum of Der p 1 and Der f 1 was reported for the National Survey of Allergens.

**TABLE E5.** Association between allergen specific sensitization (>1.0 IU IgE/mL) and case versus control with stratification by neighborhood asthma prevalence

Sensitization †	Overall LAPN and HAPN (n = 225)		LAPN (n = 111)		HAPN (n = 114)		<i>P</i> <sub>interaction</sub> between LAPN and HAPN§
	(%)	Adjusted OR (95% CI)‡	(%)	Adjusted OR (95% CI)	(%)	Adjusted OR (95% CI)	
Cockroach							
Nonasthma	7.7		3.8		11.8		
Asthma	21.5	3.45 (1.37-8.67)**	17.2	7.34 (1.28-42.0)*	25.4	3.09 (0.97-9.88)	.38
Mouse							
Nonasthma	4.8		5.7		3.9		
Asthma	14.9	2.95 (1.02-8.51)*	10.3	2.03 (0.45-9.19)	19.0	5.64 (1.08-29.4)*	.45
Dust mite							
Nonasthma	12.5		15.1		9.8		
Asthma	24.8	2.57 (1.20-5.50)*	29.3	2.94 (1.01-8.54)*	20.6	2.72 (0.83-8.96)	.89
Cat							
Nonasthma	10.7		9.6		11.8		
Asthma	21.5	2.17 (0.97-4.86)	20.7	2.63 (0.69-10.1)	22.2	2.28 (0.73-7.19)	.75
Dog							
Nonasthma	5.8		3.8		7.8		
Asthma	21.5	3.93 (1.50-10.32)**	17.2	5.00 (0.97-25.7)	25.4	4.07 (1.15-14.4)*	.70
Any indoor							
Nonasthma	24.0		22.6		25.5		
Asthma	47.1	2.75 (1.49-5.07)**	50.0	4.63 (1.73-12.4)**	44.4	2.52 (1.02-6.20)*	.34
Ragweed							
Nonasthma	4.8		1.9		7.8		
Asthma	13.2	2.73 (0.93-8.02)	20.7	13.9 (1.61-119)*	6.3	0.59 (0.12-2.85)	.015
Any allergen							
Nonasthma	24.0		22.6		25.5		
Asthma	52.1	3.42 (1.85-6.30)***	60.3	7.67 (2.77-21.3)***	44.4	2.52 (1.02-6.20)*	.099

\**P* < .05; \*\**P* < .01; \*\*\**P* < .001.

†Children were considered sensitized to an allergen if they had &gt;1.0 IU/mL IgE against that allergen.

‡ORs were adjusted for race, Hispanic ethnicity, sex, maternal asthma, and cockroach, mouse, dust mite, and cat allergen concentrations in bed dust in logistic regression.

§Effect modification by neighborhood asthma prevalence was tested by using a multiplicative interaction term of allergen sensitization by neighborhood asthma prevalence group in logistic regression models.