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Pyrethroid Exposure among Children Residing in Green versus Non-Green Multi-Family, Low-Income Housing

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Abstract

Background: There is growing concern about children's chronic low-level pesticide exposure and its impact on health. Green building practices (e.g. reducing leakage of the thermal and pressure barrier that surrounds the structure, integrated pest management, improved ventilation) have the potential to reduce pesticide exposure. However, the potential impact of living in green housing on children's pesticide exposure is unknown.

Objective: To address this question, a longitudinal study of pyrethroid metabolites (3-phenoxybenzoic acid [3-PBA], 4-fluoro-3-phenoxybenzoic acid [4-F-3-PBA], *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid [*trans*-DCCA]) in first morning void urine, collected from 68 children from New Orleans, Louisiana residing in green and non-green housing was conducted.

Methods: Children were followed for one year with three repeated measures of pesticide exposure. Generalized Estimating Equations examined associations between housing type (green v non-green) and urinary pyrethroid metabolite concentrations adjusting for demographic and household factors over the year.

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Competing Financial Interests Declaration

The authors declare no actual or potential competing financial interests.

Results: Ninety-five percent of samples had detectable concentrations of 3-PBA (limit of detection [LOD]: 0.1 μg/L); 8% of 4-F-3-PBA (LOD: 0.1 μg/L), and 12% of *trans*-DCCA (LOD: 0.6 μg/L). In adjusted models, green housing was not associated with statistically significant differences in children's 3-PBA urinary concentrations compared to non-green housing.

Significance: In this study, green building practices had no impact on children's pyrethroid urinary concentrations. Further studies with larger sample sizes are needed to confirm these findings.

Keywords

urinary metabolites; children; pyrethroids; urban; green housing

Introduction

It has long been established that there is a link between housing and health. For example, radon, lead, and cockroach allergen are associated with lung cancer, neurological effects, and asthma morbidity, respectively.(1) There is growing evidence suggesting the home may be an important reservoir of chemical exposures, particularly for children -- who represent a vulnerable group.(2–4) Children are exposed to chemical stressors from the food they eat, water they drink, air they breathe, and surfaces they touch (chemical residues on surfaces or in dust and soil). Life stage-specific diet, activities, and behaviors influence the nature and extent of their exposures.(5) Furthermore, children in the United States (U.S.) spend approximately 90% of their time indoors, with a majority of that time in their own home.(6) A specific concern is exposure to pesticide residues, ubiquitous in U.S. homes due to widespread use in and around the house to control for cockroaches, mice, bedbugs, ants, fleas, and other pests.(3)

The United States Environmental Protection Agency (EPA) estimates that 88 million households use pesticides.(7) Given such widespread use, the lack of data quantifying differences in residential exposure via human biomonitoring studies (i.e., measuring chemical biomarkers in samples including blood or urine) is an important data gap(8) particularly in urban, multi-family housing where pest infestation is a chronic problem.(9,10)

Pyrethrins and their synthetic derivatives, pyrethroids, are an important insecticide class for public health (e.g., mosquito control) and frequently used in residential settings because of their relatively low environmental persistence and slow-resistance development in pests.(11) Since 2001, their use has been increasing in the U.S. as a result of government restrictions on organophosphate insecticides.(7,12) Pesticide residues from the direct use of pesticides in homes and the infiltration of pesticides from the outdoors result in a variety of potential exposure pathways.(13) Although pyrethroids are believed to have low environmental persistence compared to other classes of pesticides, pyrethroid residues have a relatively higher degree of persistence in the indoor environment because there is minimal exposure to the three primary degrading factors found outside: UV radiation from sunlight, hydrolysis associated with water, and microbial degradation in soil.(14–16) Nakagawa et al. showed that permethrin, a common pyrethroid, persisted on residential surfaces for 112 days (the

entire study period) in concentrations up to 61.7% of the initial concentration(17) and Shin et al. showed that permethrin persisted in the indoor environment for up to 3.8 years.(18) Therefore, the home may become a reservoir for pyrethroid exposures.

The primary human routes of exposure to pesticides are inhalation, dermal, and ingestion. Ingestion via food is considered the most important exposure route for the general population.(19) However, because of child-specific activities and behaviors, respiratory routes and non-dietary pathways associated with hand-to-mouth and object-to-mouth activities may also be important pathways for children.(20) Chronic, low-level pesticide exposures may be of particular concern for children because the processes of metabolism and elimination are less developed than those of adults.(19) For children who live in urban, low-income and/or multi-family housing, the risk may be even higher because pest infestation is a persistent problem resulting in increased pesticide use.(21) Therefore, evaluating factors associated with housing and pesticide exposure may be informative for developing strategies aimed at protecting the well-being of this vulnerable group by increasing the evidence base concerning the effects of green housing on pesticide exposure.

Green building practices focus on energy efficiency, reduced water consumption, a reduced environmental footprint, and reduced human exposure to chemicals. Green buildings practices pertinent to this study incorporate the adoption of integrated pest management (IPM) as a pest control strategy(22) including limiting chemical pest control methods by implementing alternative methods such as sealing cracks and using non-chemical means of pest control. Studies suggest that homes built to green standards have lower levels of particulate matter, allergens and volatile organic compounds (VOCs) and aldehydes.(23,24) But the evidence for pesticides is lacking. Adequate ventilation, nonchemical methods of pest control, and integrated pest management are suggested pathways to reduce indoor pesticide exposure, (25) all of which are components of green building practices. The green building strategy of “tightening the building envelope” to reduce leakage of the thermal and pressure barrier that surrounds the structure may reduce pesticide infiltration from outdoor sources and may also prevent pests from entering the home thus reducing the need to apply pesticides. On the other hand, it may inadvertently result in an accumulation of pesticides indoors. Given that building practices include features associated with reductions in residential pesticides, we hypothesized that these features would reduce human exposure. However, to our knowledge there are no data on whether green building practices result in reduced human exposures to pesticides.

Our study objective was to quantify urinary concentrations of biomarkers of pesticide exposure in children living in green housing and compare concentrations to children living in non-green housing to assess whether green building practices are associated with children’s exposure to pesticides.

Subjects and Methods

Study Design.

Data were collected as part of the Green Housing Study (GHS), a multi-city longitudinal repeated measures cohort study comparing the level of chemical and biological agents in

green versus non-green, multi-family, low-income housing. Data used in this analysis are from New Orleans, Louisiana, one of three study sites included in the GHS. Each home was visited three times (baseline, 6 months, and 12 months).

Eligible Homes.

Homes eligible for participation in the GHS included dwellings in Housing and Urban Development (HUD) subsidized, multi-family housing complexes. For this study, green housing inclusion criteria were defined as a minimum of a home constructed using low volatile organic compound (VOCs) materials and using IPM as the pest control method. In 2009, The Housing Authority of New Orleans completed the first of many redevelopments of its public housing stock using green building practices. The housing complexes included in the study were built to Enterprise Green Community Criteria (EGC) 2011 standards or Leadership in Energy and Environmental Design (LEED) certification. Study participants in green homes were recruited from these developments. Participants in non-green homes lived in HUD subsidized, multi-family housing that did not employ green building practices and which were located in New Orleans. Participants were recruited through collaborations with community partners. We hosted and participated in health fairs and other community gatherings. We worked closely with the residents' council of several housing developments who were concerned about the impact of housing on their children's health. All participants were compensated for their participation in the form of a $50 gift card from a local vendor..

Study Population.

Children, 7 – 12 years old with doctor-diagnosed asthma who had experienced asthma-related symptoms (wheezing, slow play, or night awakenings) during the previous 6 months and who lived in HUD-subsidized homes, were eligible to participate in the study. Sixty-eight participants were recruited between September 2014 and June 2015. The study was approved by the Centers for Disease Control and Prevention's (CDC) and Tulane University Biomedical Institutional Review Boards (IRB No: 624114) as well as the U.S. EPA's Human Subjects Research Review Official. Written consent and assent were obtained from each caregiver and child.

Socio-Demographic Data.

Socio-demographic information, including child's age, race and sex, and household income, was collected via questionnaire administered at each visit by trained field staff. Additional information collected via questionnaire included number of people residing in the home and the date the child began residing at the home. Child's height and weight at each visit was measured using standard protocols and body mass index (BMI) was determined based on CDC growth charts.(26)

Environmental Data.

Information on residential pesticide use was collected by field staff at each visit via a structured home environment questionnaire. Primary caregivers were asked if any pest control measures, by either a member of the household or professional pesticide applicators, had been used to control pests (i.e., cockroaches, ants, bedbugs, other insect pests or rodents)

in the previous six months. Caregivers answering yes were then asked about the specific pest control method used (e.g., sticky traps, bait traps, gel, spray). Besides the use of pesticide and the type of pesticide (e.g spray, bait, trap etc.), no additional information was collected.

Pest activity can be strongly influenced by season, therefore, home visit season was a covariable defined using the northern meteorological seasons: Spring: March 1st to May 31st; Summer: June 1st to August 31st; Fall: September 1st to November 30th; and Winter: December 1st to February 28th.(27)

Quantification of Urinary Pesticide Biomarkers.

Two urine samples (a convenience spot sample and a first morning void [FMV] spot sample) were collected at each home visit. The convenience spot sample consisted of the child providing a urine sample while the field staff were in the home. The FMV consisted of the technician leaving a sterile urine cup with instructions for the mother/primary caregiver to obtain a urine sample from the child upon awakening. The two urine samples were collected within 5 days of each other. FMV samples were stored in the participant's home freezer until pick-up by study personnel on the 5th day. Urine samples were transported to Tulane University's School of Public Health and Tropical Medicine on ice packs and stored at −80 °C until being shipped to the CDC's Division of Laboratory Sciences for analysis. FMV samples were used for exposure measurements in this analysis because they better reflect household exposure due to the short half-life of urinary pesticide metabolites(<24hrs).(28)

Urine samples were analyzed as described by Davis et al. (2013) using a semi-automated solid phase extraction method coupled with isotope dilution for the mass spectrometric quantification of specific synthetic pyrethroids biomarkers.(29) Three pyrethroid metabolites were measured: 4-fluoro-3-phenoxybenzoic acid (4-F-3-PBA): a metabolite of cyfluthrin and flumethrin; *trans*-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (*trans*-DCCA): a metabolite of cyfluthrin, permethrin, and cypermethrin; and 3-phenoxybenzoic acid (3-PBA): a non-specific metabolite for 18 of the currently used pyrethroids that are applied in residential and/or agricultural settings.(30) The limits of detection (LOD) were 0.6 μg/L for *trans*-DCCA and 0.1 μg/L for 3-PBA and 4-F-3-PBA.

Creatinine was measured at CDC using a Roche/Hitachi Cobas® c501 chemical analyzer (Roche Diagnostics, Inc., Indianapolis, IN) using an enzymatic method. The reportable range of creatinine in urine was 1.1–610 mg/dL, and inter-assay coefficients of variation were less than 2%. The results of this procedure are traceable to the isotope dilution-mass spectrometry reference method. (31)

Quality Assurance/Quality Control

Pyrethroid metabolites were quantified using calibration curves built with the peak area ratio of each analyte to its corresponding isotopically labeled internal standard versus standard concentration. Calibration curves were prepared daily and included twelve standard solutions containing all analytes and encompassing the entire linear range of the method (0.1–50 μg/L). Two low concentration quality control materials (QCs), two high concentration QCs, matrix blank, solvent blank and a standard check sample were analyzed

concurrently with up to 72 study samples and calibration standards per run. For each analytical run, concentrations of reagent blanks were examined. Samples with concentrations above the calibration curve were re-extracted with a smaller sample volume to bring the result within the reportable range. Concentrations of QC materials were averaged to obtain one measurement of high- and one of low-concentration QC for each run and these concentrations were evaluated with standard statistical probability rules to monitor precision of the analytical measurements.(32)

Statistical Analysis.

Descriptive statistics included measures of central tendency: means, geometric means and standard deviations (SD) or medians and 95% confidence limits for continuous variables and number and proportion for categorical variables. Non-creatinine adjusted pesticide metabolite concentrations (μg/L) were reported for each urine sample. For reporting geometric means, metabolite concentrations below LOD were imputed as LOD/√2.(33) Metabolites with greater than 60% of values below the LOD were excluded from regression analyses. At baseline, chi-square or Fisher's exact tests were used to assess differences between housing type (green vs. non-green) for categorical variables. For continuous variables, a two-sample t-test or Kruskal-Wallis test was used to assess statistical differences. At each time point, overall correlations between biomarker concentrations in FMV and convenience spot samples were assessed using Pearson's r- correlation for natural log-transformed urine metabolites. To calculate the intra-class correlation coefficient (ICC) a one-way random effects model was used to estimate within-person variance in pyrethroid biomarker concentrations at baseline, 6 months, and 12 months. ICCs can range from 0 to 1; ≥ 0.75 indicates excellent reproducibility and ≤ 0.4 indicates poor reproducibility.(34)

4-F-3-PBA and trans-DCCA were excluded from regression analyses because more than 60% of samples were below the LOD. For 3-PBA, concentrations were natural log-transformed to normalize the data and individual models were constructed. Normal distribution of natural log transformed 3-PBA was assessed using the Shapiro-Wilk (SW) test. Bivariate and multivariable analyses were conducted using generalized estimating equation (GEE) models with compound symmetry correlation to account for repeated measures of pesticide biomarkers concentrations. All GEE models controlled for time-varying factors. Creatinine level was included in all models and housing type was included in all multivariable models. Child age, BMI, sex, caregiver education, annual household income, building type, location of child's bedroom, presence of furry pets, reporting seeing roaches, pesticide use, presence of smoker in the home, season, and number of days child spent a majority of the time in the home were considered as potential confounding variables and were included in multivariable models if they were associated ($p<0.20$) with urinary metabolite concentrations in bivariate analyses. We used a conservative cut point in order to avoid excluding potential confounders in multivariable models.(35) All analyses were completed in SAS 9.4 (Cary, North Carolina).

Results

Demographic characteristics of the 68 children (100% black race, mean age = 9.6 years, 53% female) are presented in Table 1. Twenty nine percent of children were overweight or obese. Most caregivers had a high school diploma or greater (76%) and a majority of households reported an annual household income <$5,000 per year (69%).

At baseline, season, building type, and location of child's bedroom were significantly different between green and non-green homes. Most baseline visits for green homes (63%) occurred in spring and most non-green home (55%) baseline visits occurred in winter. Green homes were more likely to be in an apartment building and children's bedrooms were more likely to be on the second floor in these homes. There were no significant differences in child age, number of residents, or years in home between green and non-green homes. One non-green home participant reported time inhabiting residence of 35 years and was considered an outlier but was not removed from analysis. Median time participants resided in home was not significantly different between green (3.0 years) and non-green homes (2.0 years).

A total of 202 FMV and 203 convenience spot urine samples were collected over the 12-month follow-up. Sixty-six participants had all 6 urine samples collected. One participant was lost to follow-up at month 12 and one participant failed to provide a FMV sample at baseline. FMV and convenience samples were highly correlated (4-F-3-PBA: r=0.78, p<0.0001; 3-PBA: r=0.63, p<0.0001; *trans*-DCCA: r=0.62, p<0.0001) over the entire study period and at each time point (results not shown). The SW test p-value for log transformed 3-PBA was 0.12. The within-person variance (ICC) for 3-PBA was 0.12. Most children (90–98%) had at least one pesticide metabolite detected in a urine sample collected at each home visit (Table 2). The most frequently detected metabolite was 3-PBA. Over the 12-month follow-up, 95% of samples had detectable concentrations of 3-PBA; 8% of samples had detectable concentrations of 4-F-3PBA, and 12% of samples had detectable concentrations of *trans*-DCCA. For 3-PBA and 4-F-3PBA, there were no statistically significant differences in detection frequency between children residing in green versus non-green homes. For *trans*-DCCA, there was a higher proportion of children with detectable concentrations living in non-green homes (24% vs. 6%) at the six-month visit (p=0.04). Over the entire study period, non-green homes had a higher proportion of children with detectable concentrations of *trans*-DCCA (14% vs. 10%, p=0.08) compared to green homes. Mean differences in urinary concentration between children in green and non-green housing were not statistically significant for 3-PBA (Figure 1) at any time point.

Examining the relationship between housing and demographic factors and pesticide concentrations across the entire study period (Table 3), differences were non-statistically significant for 3-PBA concentrations in green housing compared to non-green housing (1.00 μg/L vs. 0.95 μg/L, p=0.68). Other factors associated (p<0.20) with 3-PBA concentration included: building type, presence of furry pets, presence of a smoker in the home, season, and the number of days the child reported spending most of the time in the home (Table 3). In models adjusted for building type, presence of furry pets, presence of smoker in home, season, and days child spent a majority of time at home (Table 4), 3-PBA concentrations of

children residing in green housing were not different (β= 0.002, p=0.89) from children residing in non-green housing.

Discussion

Exposure to 3-PBA precursors was ubiquitous for children living in both green and non-green homes. This finding is consistent with data from the National Health and Nutrition Examination Survey (NHANES) showing 3-PBA to be the most frequently detected pyrethroid biomarker in the general population.(36) Using data from NHANES 2009–2010, 3-PBA concentrations of children in this study are almost twice as high (FMV median 1.02 μg/L, 95% CI: 0.87,1.25; convenience spot median 0.88 μg/L 95% CI 0.80,1.02) as children aged 6–11 in the general population (median 0.48 μg/L, 95% CI: 0.35,0.70).(37) More recent data from NHANES 2007–2012(38) reveal similar findings. Overall, the median urinary 3-PBA for children 6–11 years was 0.49 μg/L (IQR: 0.18 – 1.52). For non-Hispanic black children 6–19 years of age the median was 0.48 μg/L (IQR: 0.07 – 1.11). These results show that children in the current study have 3-PBA concentrations almost twice as high as the general population of U.S. children in 2007–2012. In a study by Bradman et al.(39) the geometric mean urinary 3-PBA in children 3–6 years residing in a low-income urban environment (Oakland, CA) was 0.76 μg/L (95% CI: 0.60, 0.97), which was lower than the current study geometric mean for FMV 1.05 μg/L (95% CI: 0.87,1.27) and convenience spot sample geometric mean (1.18 95% CI: 0.95,1.48). Children residing in an agricultural environment (Salinas, CA) had even lower geometric mean concentrations of 3-PBA (0.42, 95% CI: 0.34 – 0.52). These results along with high frequency of detection suggest that children in the present study may be more highly exposed than the general population.

This study utilized a repeated measures design. This is important because we found that urinary 3-PBA level is not consistent throughout the year. The intra-class correlation coefficient (ICC) for the natural log-transformed concentration of 3-PBA was 0.12 indicating concentrations from a single sample do not represent typical exposures over the year. However, convenience and FMV spot samples were highly correlated at each time point so either could be used as a measure of exposure. Due to the dynamic recruitment and year of follow up both green and non-green housing had seasonal variation when samples were taken. 45% of samples in green homes were taken in spring, 12% in summer, 29% in fall, and 16% in winter. In non-green homes 25% were obtained in spring, 18% in summer, 20% in fall and 36% in winter. Although reported pesticide use was greater in summer (data not shown), the median urinary concentrations of 3-PBA did not vary by season.

We also observed suggestive differences in the proportion of children with detectable concentrations of *trans*-DCCA by housing type at individual time points and across the entire study period, although overall only 12% of samples had detectable concentrations. These are important observations for future studies when considering use of a single metabolite at a single time point as the exposure metric. This study shows that the proportion of samples with detectable concentrations as well as the concentration of commonly detected pyrethroid metabolites can change considerably over time. When using biomarkers to represent an individual's exposure to chemicals with a relatively short half-life, the within-person variability, if not properly accounted for could lead to exposure measurement

error or misclassification and obscure results of epidemiologic investigations and assessment of risk.(40) As shown in the current analysis, we observed differences in detection frequencies and concentrations even within the same pesticide class. However, the differences should be considered with caution because of the small sample size.

There appeared to be no difference in 3-PBA concentration between children residing in green versus non-green homes when controlling for demographic and household factors previously shown to be associated with urinary metabolite concentrations. This may be due, at least in part, to the lack of data on all sources of pyrethroids, including diet. If diet is the primary source of pyrethroid exposure for this population, the relatively small sample size may not have been sufficient to detect any differences in concentration related to building type.

Improvements in air quality, reductions in allergens, particulate matter, black carbon, nitrogen dioxide, and some volatile organic compounds have been associated with green housing practices.(24,41) These studies primarily used environmental (indoor air and surface media samples) data as a proxy for human exposure. Previous studies have also examined the predictors of pyrethroid metabolite concentration and found that season, owning a furry pet, diet, and pesticide are associated with urinary biomarkers(42–44) but to our knowledge, this is the first study to look at the impact of green building practices on pesticide biomarkers in children. In contrast to previous studies of urinary biomarkers, in adjusted models we did not find significant differences in season, presence of a furry pet, or pesticide use. However in unadjusted models, residing in an apartment was associated with higher 3-PBA concentrations which is consistent with previous study findings of increased pest-related problems in multi-family complexes.(9)

The lack of differences in concentrations of pyrethroid pesticide urinary markers by housing type when controlling for other demographic and household factors suggests that unlike other chemicals in the home, green housing practices like IPM that rely on physical barriers and alternatives to pesticide sprays alone may not reduce exposures to pyrethroid pesticides in children. However, caution must be taken when interpreting these results as environmental exposures are complex and detecting differences or lack thereof does not necessarily mean that exposure was or was not caused by housing type. Studies have shown improved air exchange and lower emissions from the materials used in green buildings can reduce indoor exposures, however indoor exposure encompasses not only the building structure but occupant activities as well.(24) Therefore, best practices to improve the indoor environment include multilevel interventions such as complex wide IPM strategies in multifamily housing and individual education on pesticide use and exposure sources to reduce exposures.(45)

An unexpected finding from this study was that during the 12-month follow-up, participants living in green housing were twice as likely to report the use of spray pesticides compared with those in non-green housing, despite not reporting seeing pests more frequently (data not shown). This is unexpected considering the green building practices include IPM strategies which should limit the need for spraying pesticides. The reasons behind these finding were outside the scope of the study but suggest the need for research on the role of pesticide use behavior and the risk of pesticide exposure. The increased use of pesticides in green homes

may have contributed to the absence of difference in urinary metabolite concentrations observed between children residing in green and non-green homes; however, the current study was not designed to discern sources of pesticide exposure.

This study has several limitations. Due to the rapid rate of metabolism, we may not have adequately represented typical exposure over a year, however the use of repeated exposure measurements is a strength.(46) The lack of statistically significant differences could be due to limited variability in exposure which results in reduces power. The study lacks data on diet. However, studies suggest that non-dietary routes of pyrethroid exposure may be significant in certain instances for children.(47) An additional limitation is the crude assessment of pesticide use, no data on application dates or amounts were obtained during the study therefore our assessment was limited to reported pesticide use in the previous 6 months. Another limitation of the current analysis is the lack of a systematic definition of green building practices. Therefore the lack of difference between green and non-green housing could be due to the heterogeneity of green characteristics between different housing complexes.

Strengths of the study include the use of urine pesticide metabolite concentrations as the exposure variable. Relying on concentrations of pesticide metabolites in biospecimens is desirable because such concentrations account for all possible exposure routes and reflect the interindividual differences in uptake and genetic susceptibility.(48) To our knowledge, there is only one study that assessed urinary metabolite concentrations of children in an urban setting focused on low-income housing.(39) That study however, focused on differences in metabolite concentrations between participants consuming either a conventional or an organic diet and did not consider green building practices. Another strength of the current study is the longitudinal repeated measures design. Due to the short half-life of urinary metabolites of pesticides, a longitudinal design has the advantage of reducing random error that may arise in cross sectional studies.(49)

Assessing housing factors associated with pesticide exposure is important due to widespread use in the home although there is inconsistency in the association with health. In a recent qualitative review of pyrethroid exposure and health, Burns and Pastoor found inconsistencies between findings from epidemiologic studies and those from toxicological studies in animal models.(50) Contrary to epidemiologic findings, the authors indicate that pyrethroids would not have an adverse effect on birth outcome and infant health at birth or are unlikely to induce allergic or asthma response. However two additional systematic reviews(15,51) identified several health outcomes associated with pyrethroid exposures ranging from reduced male reproduction and fertility to birth and neurodevelopmental outcomes. With the uncertainty surrounding the impact of exposure to pyrethroids on human health, and the chronic nature of exposure, additional research in this area is warranted, particularly as it relates to children’s long-term health and wellbeing.

Our hypothesis that pesticide biomarker concentrations would be lower in children aged 7–12 years living in housing built to green standards compared to other children was not supported. The reasons for our findings may be due to different pathways of pesticide exposure and different household behaviors, including increased pesticide use by residents

in green homes. The children in the current study, in both green and non-green homes, had higher urinary concentrations of 3-PBA compared to the general population of children from NHANES and the reasons behind the higher concentrations are an important note for future research. Additional data on the individual factors associated with urinary pesticide metabolite concentrations could help fill research gaps particularly for children in low-income housing who are likely more vulnerable to the effects from chronic pesticide exposures.

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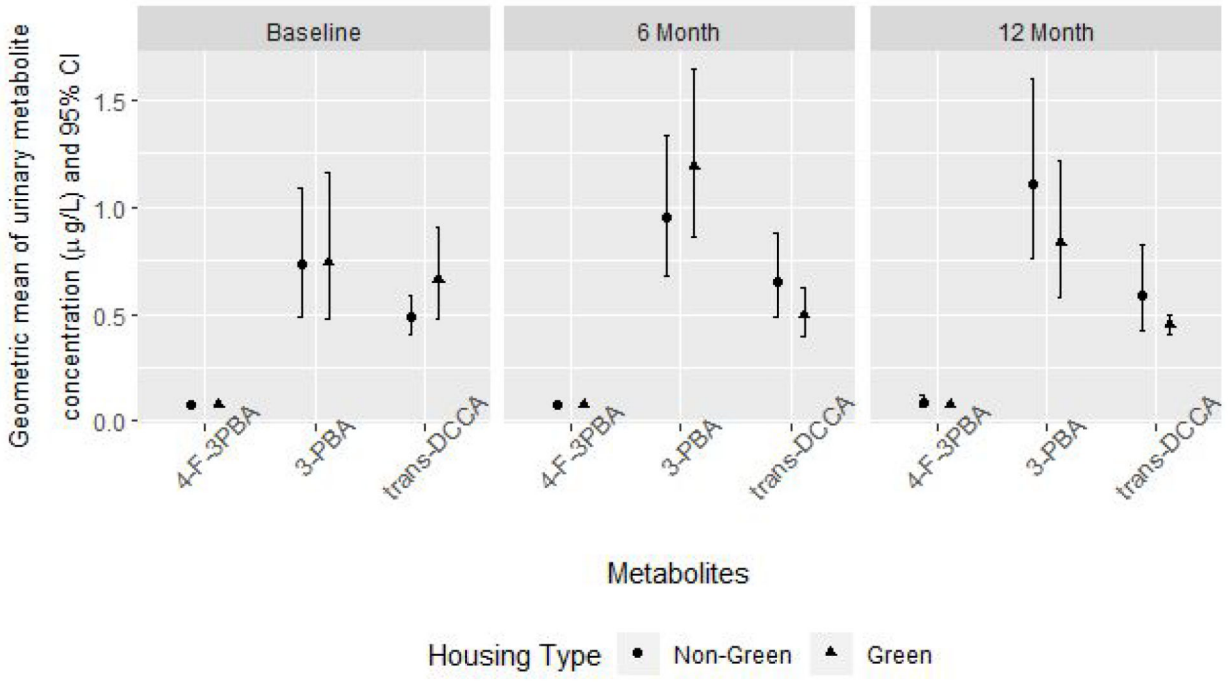

a. 8% of samples above LOD for 4-F-3PBA and 12% above LOD for *trans*-DCCA; geometric means and CI include imputed levels as LOD/√2

Figure 1.
Geometric mean urinary metabolite concentrations by visit and home type (N=202)[a]

Table 1.

Characteristics of children and homes at baseline (N=68)

	Total (N=68)	Green (N=35)	Non-Green (N=33)	p-value[a]
		mean (SD)		
Child Age	9.6 (1.7)	9.69 (1.75)	9.44 (1.64)	0.55
Number of People in Home	4.1 (1.7)	4.03 (1.72)	4.15 (1.64)	0.76
Time in Home (Years)	3.7 (8.0)	2.71 (1.71)	4.7 (11.34)	0.32
		n (%)		
Child Black Race	68 (100)	35 (100)	33 (100)	-
Child BMI				0.50
Underweight	8 (12)	6 (17)	2 (6.1)	
Normal	40 (59)	18 (51)	22 (67)	
Overweight	9 (13)	5 (14)	4 (12)	
Obese	11 (16)	6 (17)	5 (15)	
Child Sex				0.22
Female	36 (53)	16 (46)	20 (61)	
Male	32 (47)	19 (54)	13 (39)	
Caregiver Education				0.86
Less than High School	16 (24)	7 (20)	9 (27)	
High School Graduate	30 (44)	16 (46)	14 (42)	
Greater than High School	22 (32)	12 (34)	10 (30)	
Annual Household Income				0.76
< $5,000	47 (69)	26 (74)	21 (64)	
$5,000–9,999	8 (12)	4 (11)	4 (12)	
$10,000–14,999	8 (12)	3 (8.6)	5 (15)	
≥$15,000	5 (7)	2 (5.8)	3 (9.1)	
Building Type*				0.01
A one-family house detached from other house	1 (1.5)	0 (0)	1 (3.1)	
A one-family house attached to one or more houses	25 (37)	7 (20)	18 (56)	
A building with two apartments (or a 2-family house)	19 (28)	14 (40)	5 (16)	
A building with three or more apartments	22 (33)	14 (40)	8 (25)	
Floor Location of Child's Bedroom*				<0.01
1st Floor (Ground)	32 (48)	8 (23)	24 (75)	
2nd Floor	35 (52)	27 (77)	8 (25)	
Furry Pets Present				0.26
Yes	8 (12)	6 (17)	2 (6.3)	
No	59 (88)	29 (83)	30 (94)	
Seen Roaches Past 6 Months				0.34
Yes	21 (31)	9 (26)	12 (36)	
No	47 (69)	26 (74)	21 (64)	

	Total (N=68)	Green (N=35)	Non-Green (N=33)	p-value[a]
		mean (SD)		
Pesticide Use Last 6 Months				0.16
No Use	31 (46)	13 (38)	18 (55)	
Non-spray use	6 (9.0)	3 (8.8)	3 (9.1)	
Spray Use	30 (45)	18 (53)	12 (36)	
Smoker in Home				0.48
Yes	17 (25)	10 (29)	7 (21)	
No	51 (75)	25 (71)	26 (79)	
Season*				0.05
Winter (Dec-Feb)	26 (39)	8 (23)	18 (55)	
Spring (Mar-May)	32 (47)	22 (63)	10 (30)	
Summer (Jun-Aug)	1 (1.5)	1 (2.9)	0 (0)	
Autumn (Sep-Nov)	9 (13)	4 (11)	5 (15)	
Number of days child spent majority of daytime hours (6am-6pm) at home				0.69
0	0 (0)	0(0)	0(0)	
1	12 (18)	7 (20)	5 (15)	
2	31 (46)	18 (51)	13 (39)	
3	3 (4.4)	1 (2.9)	2 (6.1)	
4	6 (8.8)	2 (5.7)	4 (12.)	
5	16 (24)	7 (20)	9 (27)	

[a] P value significant at $p<0.05$

* significant difference between green and non-green housing

Table 2.

Number and proportion of children with first morning void urinary pesticide metabolites concentrations greater than limit of detection (LOD) by visit and home type

Metabolite	LOD (μg/L)	Baseline N=67				6 Month N=68				12 Month N=67				Study Period N=202			
		Total	Green	Control	p[a]	Total	Green	Control	p[a]	Total	Green	Control	p[a]	Total	Green	Control	p[b]
4-F-3PBA	0.1	3 (4.48)	1 (2.94)	2 (6.06)	0.61	5 (7.35)	3 (8.57)	2 (6.06)	0.99	7 (10.45)	5 (14.29)	2 (6.25)	0.43	15 (7.43)	9 (8.65)	6 (6.12)	0.54
3-PBA	0.1	60 (89.55)	30 (88.24)	30 (90.91)	0.99	67 (98.53)	35 (100)	32 (96.97)	0.48	64 (95.52)	32 (91.43)	32 (100.00)	0.24	191 (94.55)	97 (93.27)	94 (95.92)	0.72
trans-DCCA	0.6	9 (13.43)	7 (20.59)	2 (6.06)	0.15	10 (14.71)	2 (5.71)	8 (24.24)	0.04	5 (7.58)	1 (2.94)	4 (12.50)	0.19	24 (11.94)	10 (9.71)	14 (14.29)	0.08

[a] Fisher's Exact Test

[b] Type 3 Effect, Generalized Estimating Equations (GEE)

4-F-3PBA: 4-fluoro-3-phenoxybenzoic acid; 3-PBA: 3-phenoxybenzoic acid; *trans*-DCCA: *trans*-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid

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Table 3.

GEE analysis of first morning void urinary pyrethroid biomarker concentration (μg/L) by demographic and household factors (N=68 children, 202 urine samples)[a]

	3-PBA			
	n (N=191)	Median[b]	95% CI	p-value[c]
Child BMI				0.45
Underweight	17	2.47	0.50–3.02	
Normal	118	0.95	0.83–1.17	
Overweight	26	1.08	0.56–1.97	
Obese	30	0.87	0.68–1.3	
Child Sex				0.69
Female	99	0.95	0.86–1.17	
Male	92	0.96	0.75–1.45	
Caregiver Education				0.87
Less than High School	46	1.16	0.82–1.56	
High School Graduate	87	0.95	0.76–1.44	
Greater than High School	58	0.93	0.77–1.12	
Household Income				0.27
< $5,000	134	0.91	0.81–1.12	
$5,000–9,999	19	0.68	0.33–1.9	
$10,000–14,999	23	1.28	0.81–1.69	
>$15,000	15	1.05	0.81–3.06	
Building Type				0.05
A one-family house detached from other house	3	1.73	0.62–11.9	
A one-family house attached to one or more houses	72	0.89	0.73–1.03	
A building with two apartments (or a 2-family house)	52	0.86	0.68–1.16	
A building with three or more apartments	61	1.35	1.02–2.07	
Location of Child's Bedroom				0.22
1st Floor (Ground)	90	0.94	0.82–1.15	
2nd Floor	98	1.03	0.77–1.52	
Furry Pets Present				0.16
Yes	23	1.33	0.81–3.28	
No	165	0.91	0.82–1.15	
Seen Roaches Past 6 Months				0.28
Yes	91	1.01	0.86–1.49	
No	100	0.91	0.81–1.23	
Pesticide Use Last 6 Months				0.97
No Use	58	0.90	0.82–1.06	
Non-spray use	21	1.23	0.48–1.83	
Spray Use	111	1.00	0.77–1.33	
Smoker in Home				0.18

	3-PBA			
	n (N=191)	Median[b]	95% CI	p-value[c]
Yes	54	1.03	0.86–1.52	
No	137	0.91	0.81–1.23	
Season				0.07
Winter (Dec-Feb)	51	1.12	0.82–1.64	
Spring (Mar-May)	73	0.81	0.68–1.05	
Summer (Jun-Aug)	22	0.86	0.56–1.57	
Autumn (Sep-Nov)	45	1.41	0.87–2.27	
Days child spent majority of daytime hours at home				0.17
0	3	0.46	0.21–0.80	
1	37	1.23	0.87–1.85	
2	46	1.04	0.68–1.67	
3	16	1.69	0.68–2.34	
4	21	0.93	0.63–1.64	
5	67	0.82	0.68–1.02	
Green Housing				0.68
Yes	97	1.00	0.75–1.41	
No	94	0.95	0.82–1.19	

[a] Number of samples collected was 202 from 68 children, 11 samples had 3-PBA < LOD

[b] Median value over entire study period (n=191 samples)

[c] Score Statistic p-value for bivariate GEE analysis; significant at $p<0.05$

Table 4.

Adjusted differences in ln-transformed first morning void urinary pyrethroid biomarker concentrations for children residing in green vs. non green homes[a]

	3-PBA		
	β	**95% CI**	**p-value[c]**
Building Type			0.08
A one-family house attached/detached	ref	ref	
A building with two apartments (or a 2-family house)	−0.16	−0.62–0.3	
A building with three or more apartments	0.31	−0.08–0.71	
Furry Pets Present			0.25
Yes	0.22	−0.11–0.54	
No	ref	ref	
Smoker in Home			0.19
Yes	0.22	−0.10–0.55	
No	ref	ref	
Season			0.33
Winter (Dec-Feb)	ref	ref	
Spring (Mar-May)	−0.28	−0.57–0.02	
Summer (Jun-Aug)	−0.16	−0.55–0.24	
Autumn (Sep-Nov)	−0.08	−0.48–0.32	
Days child spent majority of daytime hours at home[d]	−0.02	−0.11–0.06	0.6
Green Housing			0.89
Yes	0.002	−0.38–0.34	
No	ref	ref	

[a] Models further adjusted for creatinine

[b] Detached single family home combined with single family home for analysis due to low frequency

[c] Significant at $p<0.05$

[d] Treated as continuous variable