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Vinyl flooring in the home is associated with children's airborne butylbenzyl phthalate and urinary metabolite concentrations

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Abstract

Prior studies have shown that vinyl flooring, as well as the vinyl-softening plasticizers butylbenzyl phthalate (BBzP) and di(2-ethylhexyl) phthalate (DEHP), are associated with asthma and airway inflammation. While DEHP exposure is primarily dietary, whether home vinyl flooring contributes to indoor air and urinary metabolite concentrations for these two phthalates is unclear. Exposures to BBzP and DEHP were examined in a prospective birth cohort of New York City children (n=239) using: (1) visual observation of potential phthalate containing flooring, (2) a two-week home indoor air sample, and (3) concurrent urinary metabolites in a subset (n=193). The category "vinyl or linoleum" flooring was observed in 135 (56%) of monitored rooms; these rooms had statistically significantly higher indoor air geometric mean concentrations of BBzP

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Conflict of interest

The authors declare no conflict of interest.

(23.9 ng/m^3) than rooms with wood or carpet flooring (10.6 ng/m^3). Children from homes with "vinyl or linoleum" flooring also had significantly higher urinary BBzP metabolite concentrations than other children. Indoor air BBzP and urinary metabolite concentrations were correlated positively (Spearman's rho 0.40). By contrast, indoor air DEHP was not associated with flooring type nor with its urinary metabolite concentrations. Vinyl flooring in the home may be an important source of children's exposure to BBzP via indoor air.

Keywords

phthalates; indoor air; urine; vinyl flooring

Introduction

Phthalates are a group of related compounds with widespread residential and commercial uses such as softeners in polyvinyl chloride (PVC) plastics and vinyl flooring.[1, 2] A recent study in Sweden found that vinyl flooring in the bedroom of children 1–3 years old was associated with incident childhood asthma over a 10 year follow-up period.[3] Plastic wall materials also have been associated cross-sectionally with bronchial obstruction and persistent wheeze in children.[4, 5] The presumed important role of the phthalates in these epidemiologic associations between flooring and respiratory health has also spurred biomonitoring to better understand the specific sources, routes and health effects of the phthalate plasticizers.[2, 6] We recently reported that prenatal urinary butylbenzyl phthalate (BBzP) metabolite concentrations were associated with incident childhood asthma[7] and that children's urinary BBzP metabolite concentrations were associated cross-sectionally with airway inflammation in a New York City cohort.[8] Given the associations of vinyl flooring and biomarkers of specific phthalates with childhood asthma and respiratory symptoms, it is important to evaluate the sources of these compounds and understand potentially reducible contributions to childhood exposure.

Phthalates vary in their physical and chemical properties; these drive their wide usages and resulting patterns of human exposure. For example, while the lower molecular weight phthalates are used in personal care products, two of the higher molecular weight phthalates, BBzP and di(2-ethylhexyl) phthalate (DEHP), are added to plastics to provide flexibility. BBzP is used primarily in the production of vinyl tiles as well as in some adhesives, carpet tiles, food conveyor belts, and artificial leather.[9] DEHP is primarily used as a plasticizer in flexible polyvinyl chloride (PVC) plastics and in consumer products such as flooring, car upholstery, food packaging, toys, and medical devices.[10] Because phthalates are not chemically bound, they can leach out of these materials and contaminate food, dust, and indoor air. Although BBzP and DEHP have low volatility, both are adsorbed onto respirable particles,[11] and considerable quantities have been found in studies collecting semi-volatile and particle bound phthalates together in personal and indoor air samples in Massachusetts, California, and New York City.[12–14] Urinary concentrations of phthalate metabolites are considered the best available biomarkers of exposure because they integrate total exposure and are less prone to external contamination in sample processing and analysis than the parent compounds.[15] Previous studies have found phthalate metabolites in virtually all tested samples from pregnant women, children, and in the U.S. general population.[14, 16, 17] Studies utilizing repeated samples have shown that phthalate urinary metabolite concentrations are likely stable after long-term frozen storage.[18, 19] More importantly, concentrations from a single spot urine sample are reasonably representative of concentrations over several months in pregnant women in this cohort.[14, 20] Of interest, in another study of New York City children, urinary concentrations of the main BBzP metabolite were more reproducible than those of DEHP metabolites.[17] It has also been shown previously that pregnant women had correlated personal air BBzP and urinary metabolite concentrations but that personal air DEHP was not correlated with its urinary metabolite concentrations[14] as total DEHP exposure is thought to be overwhelmed by dietary sources (>90%) for children and adults.[21] While biomarker measures indicate ubiquitous exposure, concentrations of phthalate metabolites can vary over orders of magnitude, likely due to different patterns of exposure, uptake, and/or metabolism across the population.

In this study, we hypothesized that vinyl flooring in the home would be positively associated with indoor air concentrations of BBzP and DEHP. Second, we hypothesized that vinyl flooring would be associated with higher urinary concentrations of the BBzP metabolite, monobenzyl phthalate (MBzP), but not a major DEHP metabolite, mono(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP).

Participants and Methods

Cohort design and enrollment

Participants for this study were children in the Columbia Center for Children's Environmental Health (CCCEH) longitudinal birth cohort study.[22, 23] A total of 727 women were enrolled into the cohort during pregnancy between the years of 1998 and 2006 from prenatal clinics at two hospitals in Northern Manhattan. Eligible participants included non-smoking pregnant self-identified Dominican or African American women ages 18–35 who reported living within Northern Manhattan or the South Bronx for ≥1 year and detailed exclusion criteria have been previously reported.[22] The study was approved by the Institutional Review Boards of Columbia University Medical Center and the Centers for Disease Control and Prevention (CDC) and all participants signed an informed consent prior to enrollment. For this study, a checklist of materials that might contain phthalates in the home was added to an ongoing home visit and a subset of children (n=243) were selected who had reached the age of 5 years and had a completed checklist, collection of an indoor air sample, and child's spot urine sample. The spot urine was collected during indoor air sampling for n=193 child participants. Both analytical laboratories measuring air and urine samples were blinded with regards to information on subject exposure characteristics.

Exposure information

Child's race/ethnicity, mother's education, and marital status were based on maternal self-report. A checklist for the presence of materials in the home that are likely to contain phthalates was administered by field staff at the time of the indoor air sampling. The checklist was completed in the same room as the air sampling (usually the child's room) as well as several others in the home. It included observation of the type of flooring, plastic coverings on furniture, plastic blinds or window treatments, and plastic shower curtains. Flooring was categorized as vinyl or linoleum, wood, carpet, ceramic tile, or other. The category of "vinyl or linoleum" flooring combined these floor types in the checklist based on prior work that these materials are not easily distinguishable by visual inspection, although phthalates are added to vinyl and not linoleum flooring products.[24] Because there were only three homes with ceramic tile and one with "other" flooring in the room that was monitored, these categories were dropped from all analyses, with *n*=239 homes remaining with wood, carpet, or "vinyl or linoleum" in the monitored room.

Indoor air

Two-week integrated air samples, which collected respirable particles and semi-volatiles, were used to characterize total airborne concentrations of phthalates occurring in the home environment. Stationary air monitors were set up preferentially in the child's bedroom or main living space to sample continuously at 1.5 L/min and run for 13 to 16 days (92% of samples were 14 days) as described.[25, 26] Samplers used a $PM_{2.5}$ cyclone (BGI, Waltham, MA) with a quartz filter followed by a polyurethane foam plug (PUF) encased in a modified URG personal pesticide sampler (University Research Glassware, Chapel Hill, NC). After collection, PUFs and filters were stored at -20°C before shipment on dry ice to Southwest Research Institute in San Antonio, TX where they were extracted together before analysis with GC/MS using isotope-labeled internal standards.[14] Laboratory matrix blanks were extracted and analyzed with each batch of samples.

Urine measures

Of the 193/239 (81%) of children with spot urines collected during the two-week air sampling, 27% were collected on the first day and 47% on the last day of sampling with the remaining samples collected at clinic visits that were largely after school. Samples were stored at -80°C until shipment on dry ice to the CDC laboratory for analysis. Measurements used isotope-labeled internal standards with high performance liquid chromatography and tandem mass spectrometry.[14, 27] This analytic method can measure up to 16 phthalate metabolites. However, for the statistical analysis we considered only MBzP and MEHHP. Although DEHP has several metabolites, we used urinary MEHHP as the proxy for exposure to DEHP because it has a longer-detection half-life and higher detection frequency than mono(2-ethylhexyl) phthalate (MEHP)[28]. In this dataset (*n*=239), those two DEHP metabolites had a Spearman rank correlation of 0.87.

Statistical analysis

Because concentrations of air phthalates were non-normally distributed, we used non-parametric tests: Mann-Whitney tests for independent samples, and Spearman's rho for rank correlations. Concentrations of urinary metabolites were approximately log-normally distributed and were natural log transformed prior to analysis. Analyses were conducted using R version 2.15.2 with the beanplot and ggplot2 packages for graphics.[29–31]

Results

The 239 children enrolled ranged in age from 5.0 to 10.7 years (mean 6.5 years, 91% less than 9 years) and included more Dominican than African American children (Table 1). As the checklist was added to ongoing monitoring (2006–2011), the subset in this analysis was enrolled more recently than the remainder of the cohort but did not differ on maternal education, marital status, or race/ethnicity (all $p > 0.05$). The category "vinyl or linoleum" was the most frequently observed flooring in 56% (*n*=135/239) of the rooms monitored. Wood was the next most frequent category (33%, *n*=79/239), followed by carpet (10%, *n*=25/239). The flooring in the monitored room was representative of the flooring in the entire home ($p<0.001$); for example, 92% of homes with "vinyl or linoleum" flooring in the monitored room had the same flooring type in more than half of the total home. Socioeconomic factors did not predict flooring type in the monitored room in this urban cohort; maternal race/ethnicity, mother having ever married, or mother having completed high school were not associated with flooring type (all $p > 0.05$).

BBzP and DEHP were detected in all air samples, and MBzP and MEHHP were detected in all urine samples. Summary statistics for the concentrations of phthalates in two-week indoor air samples and metabolites from children's spot urines are shown in Table 2. The geometric mean (GM) concentration (ng/extract) in matrix blanks (*n*=102) of BBzP (39 [95% confidence interval [CI] 36–42]) and DEHP (121 [99–148]) was considerably lower than among extracts from two-week indoor air samples (BBzP, 512 [445–589]; DEHP, 2705 [2537–2886], *n*=239). Although there was evidence of sporadic contamination with BBzP and DEHP, BBzP was not detected in 89 of 102 matrix blanks and DEHP was not detected in 25 of 102 matrix blanks while both phthalates were detected in all 239 field samples. The concentrations of BBzP in indoor air were overall lower than those of DEHP ($p<0.001$).

Flooring type and indoor air phthalates

Indoor air samples from rooms with "vinyl or linoleum" flooring had a significantly higher concentration of BBzP (GM 23.9; interquartile range [9.0, 69.7] ng/m^3, *n*=135), than rooms with wood or carpet flooring (GM 10.6; interquartile range [6.9, 13.8] ng/m^3, *n*=104) ($p<0.001$, Figure 1). The rooms with "vinyl or linoleum" flooring accounted for the 18 highest concentrations of indoor air BBzP and 90% of the highest quintile (*n*=43/48). However, BBzP concentrations also spanned the range of the exposure distribution for the three types of flooring (2.4 – 464 ng/m^3). There was no significant difference between BBzP concentrations measured in rooms with carpet versus wood flooring ($p=0.55$). Also, there was no difference in the distribution of indoor air DEHP by flooring type ($p=0.66$, Figure 1).

Indoor air concentrations of BBzP and DEHP were correlated in rooms with carpet or wood flooring (rho=0.33, $p<0.001$, *n*=104, Figure 2), suggesting other shared sources of exposure in the absence of vinyl flooring. This correlation was not found in rooms with "vinyl or linoleum" flooring (rho=0.09, $p=0.31$, *n*=135) suggesting the importance of the flooring for BBzP (Figure 2). While indoor air DEHP concentrations were higher than BBzP concentrations for most samples, the opposite was true in a subset – all of which had "vinyl or linoleum" flooring (21% of "vinyl or linoleum" floored rooms, *n*=28/135).

Flooring type and urinary phthalate metabolites

The concentration of BBzP in the two-week air sample correlated positively with concurrent urinary MBzP concentration (rho=0.40, p<0.001, *n*=193, Figure 3). A similar correlation was seen in an additional set of urine samples collected five or more days before or after the air sampling (rho=0.29, p=0.19, *n*=22, median 13 days apart). The concentration of DEHP in the air sample was not correlated with concurrent urinary MEHHP (rho=0.03, p=0.72).

Urinary MBzP concentrations were also higher among children living in homes with "vinyl or linoleum" in the monitored room (GM 32.6; interquartile range [15.5, 70.9] ng/ml, *n*=110), versus the combination of carpet or wood (GM 18.3; interquartile range [9.1, 37.2] ng/ml, *n*=83) (p<0.001, Figure 4). As in the air monitoring, there was no difference in the distribution of children's urinary MBzP concentrations with carpet versus wood flooring (p=0.92). Furthermore, there was no difference in the distribution of children's urinary MEHHP concentrations with "vinyl or linoleum" in the room monitored versus the combination of carpet and wood (p=0.97).

Discussion

This study shows that vinyl flooring is an important predictor of concentrations of BBzP in home air in New York City, consistent with previous findings in both Sweden and Bulgaria.[24, 32, 33] Importantly, our biomonitoring data also demonstrate that home flooring is significantly associated with higher MBzP urinary metabolites in children, suggesting internal dose. While a recent study in Sweden also found higher urinary phthalate metabolite concentrations in infants in homes with vinyl flooring as compared to those without,[34] our study adds a demonstrated link between "vinyl or linoleum" flooring to higher air concentrations to higher urinary metabolite concentrations, thus strengthening the evidence for an airborne exposure pathway through which vinyl flooring may contribute to internal dose. Our findings that vinyl flooring may contribute via indoor air to children's exposure to BBzP but not DEHP suggests that prior studies showing an association between vinyl flooring and children's incident asthma[3, 35] and respiratory symptoms[4, 5] may be due to BBzP exposure. Thus, the additional understanding of sources of exposure and their contribution to measures of MBzP may fill a gap in the current scientific literature by providing a link between previous observations about flooring and respiratory symptoms and asthma.

The correlation in the current study between indoor air BBzP and urinary MBzP concentrations supports previous findings that the indoor environment may be an important source of exposure to BBzP via inhalation, dermal absorption, or incidental ingestion. These types of exposure patterns would be expected to be less episodic than dietary exposures.[17, 28, 36] Repeated sampling of both BBzP in two-week indoor air and urinary MBzP in maternal spot urines previously have shown good reproducibility in 2–4 samples collected over 6–8 weeks (Intraclass correlation coefficient [ICC] 0.83, *n*=32 for BBzP; ICC 0.77, *n*=48 for MBzP).[14, 20] These exceed the reproducibility of indoor air DEHP (ICC 0.48) and DEHP metabolites (ICCs 0.27 to 0.42) in the same samples. The BBzP to MBzP correlation seen here was similar but somewhat lower than seen previously in a study that measured BBzP in maternal 48-hour personal air and spot urine samples (rho=0.48, p<0.05, *n*=62), in the same pregnancy cohort.[14] In addition to differences in exposure patterns between pregnant women and children, the lower correlation of BBzP and MBzP among the children may be due to a larger mismatch in the two week duration of the stationary air monitoring versus the short biologic half-life of hours for the urinary metabolite, or to the contribution of BBzP in air from other micro-environments outside the home (e.g. school environments) that would be captured by backpack monitoring as in the previous study. The lack of a correlation between concentrations of DEHP in the indoor air samples and metabolites in urine samples is also consistent with the prior study of personal air and urine concentrations seen in the mothers in the current cohort,[14] as well as a German study measuring DEHP in sieved vacuum cleaner bag dust and spot urine samples in children (*n*=254) aged 3 to 14.[37] Consistent with these results, a European exposure model using scenario-based probabilistic source apportionment calculated that indoor air contributes 26% of children's exposure to BBzP and diet contributes 73% of exposure. By contrast, diet was estimated to contribute more than 90% of children's exposure to DEHP, with inhalation from indoor air making up the remainder.[21]

Although these results support vinyl flooring as an important source of BBzP, substantial concentrations were still measured in the indoor air of homes with no observable vinyl flooring. We speculate that shared sources of both BBzP and DEHP, such as consumer products containing plasticizers or else a shared reservoir in house dust, may explain the correlation of BBzP and DEHP concentrations in homes without vinyl flooring. We also observed considerable variability in the indoor air concentrations of BBzP among rooms with "vinyl or linoleum" flooring. Some of this may be attributable to rooms in this category actually using linoleum flooring, which would contain no plasticizers and visually differentiating these two types of flooring is a common limitation in similar studies in the absence of confirmatory chemical analysis of the flooring material.[24] The distribution of BBzP concentrations among homes with "vinyl or linoleum" flooring remained skewed after log transformation and had an appearance that would be consistent with a mixture of a log-normal distribution similar to those in carpet or wood floor homes and a second distribution that was higher and more variable. There was also no information available on the composition, brand, age, or condition of the flooring, including the presence of water damage, which may be important parameters in explaining the contribution of flooring to indoor air phthalate concentrations. Although the category of "vinyl or linoleum" flooring was quite common in this population, it is uncertain whether the types of materials used in housing in New York City would be representative of those in other areas.

Our findings are consistent with a recent Swedish study finding that urinary MBzP concentrations were higher among infants with PVC flooring in their bedroom.[34] Perhaps highlighting the importance of the home environment or international differences in building materials, a recent German study found that flooring material in 63 daycare centers was not correlated with children's phthalate metabolite concentrations, including MBzP.[38] In a recent Danish study, settled dust in homes and daycare centers, were correlated with children's urinary MBzP concentrations (rho = 0.21) but not as strongly as our observed association between indoor air and urinary MBzP.[39]

In this study, the presence of either vinyl or linoleum flooring was a sensitive but nonspecific determinant of high BBzP concentrations in indoor air. The correlation of BBzP and urinary MBzP, and the association of flooring with metabolite concentrations further support the indoor environment as a substantial and chronic contributor to children's exposure to the phthalate plasticizer BBzP, a potential risk factor for childhood asthma.

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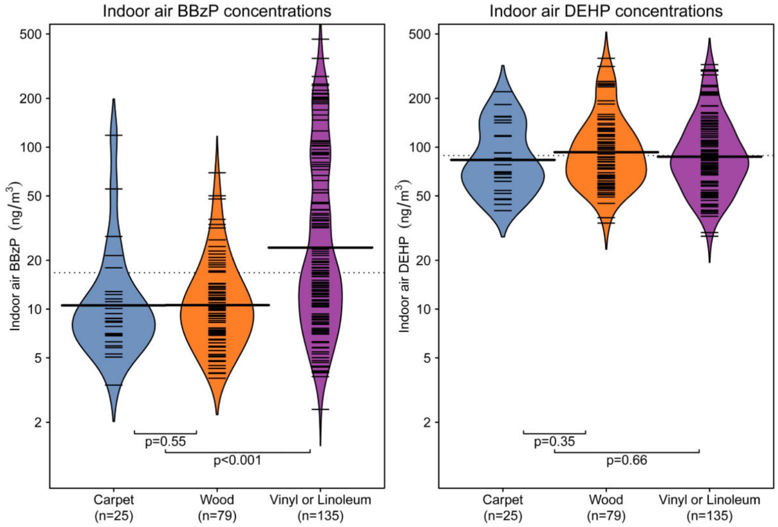

Figure 1. Distribution of BBzP and DEHP concentrations in two-week indoor air samples by type of floor in the room being monitored (*n*=239)

Each horizontal dash is one home with geometric means for each flooring type shown as darker black lines and dotted geometric means across all samples for each phthalate. The shape of the 'bean' gives the weight of the distribution from a kernel density estimate. P-values are shown from Mann-Whitney tests.

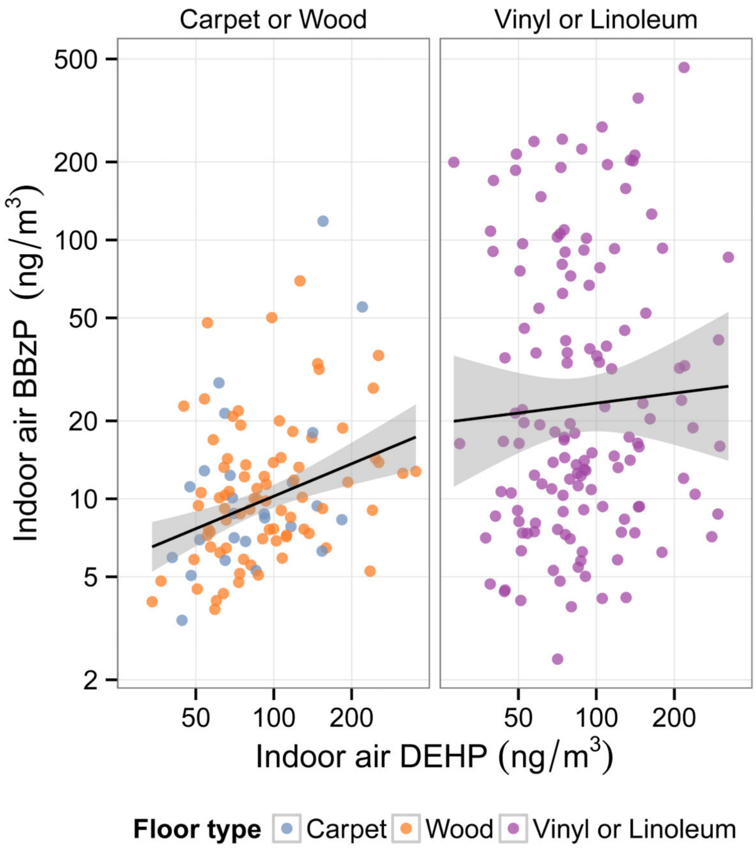

Figure 2. Association between indoor air concentrations of DEHP and BBzP stratified by floor type

Indoor air DEHP and BBzP concentrations were correlated only among those with carpet or wood (rho=0.33, p<0.001, *n*=104) and not vinyl or linoleum flooring (rho=0.09, p=0.31, *n*=135) in the room monitored. Lines show robust linear models with shaded 95% confidence intervals.

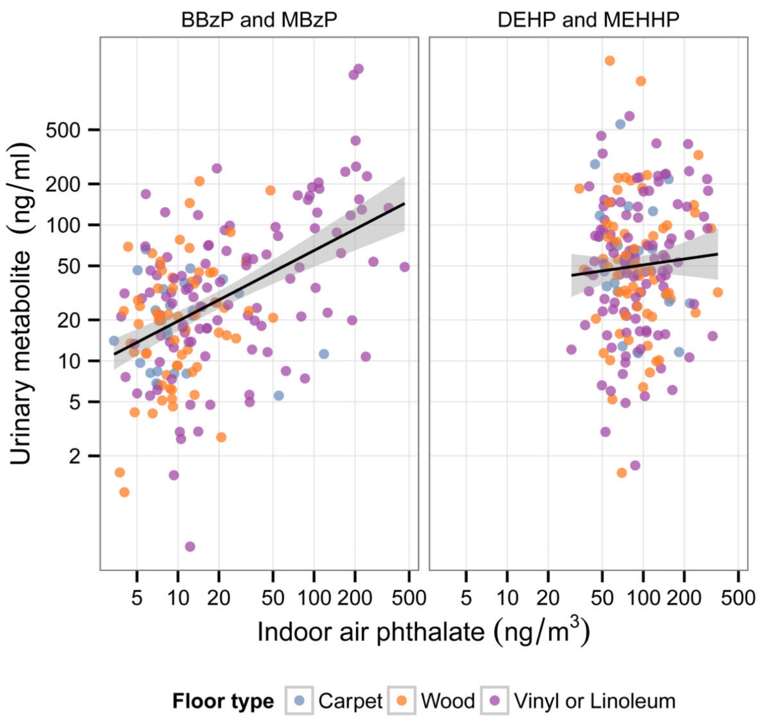

Figure 3. Association between indoor air and children's urinary metabolite concentrations for BBzP and DEHP

Indoor air concentrations of BBzP were correlated with urinary MBzP concentrations (rho=0.40, p<0.001, *n*=193). Indoor air concentrations of DEHP were not correlated with urinary MEHHP concentrations (rho=0.03, p=0.72, *n*=193). Lines show robust linear models with shaded 95% confidence intervals.

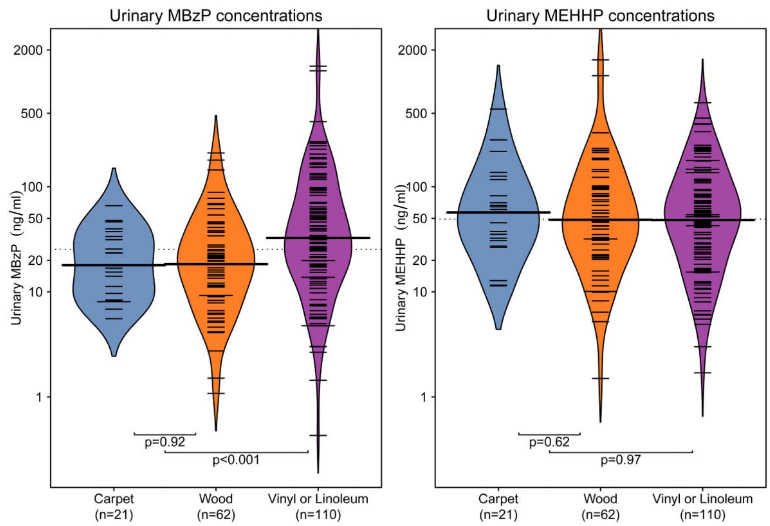

Figure 4. Distribution of MBzP and MEHHP concentrations in spot urine collected during the air sampling by type of floor in the room being monitored (*n*=193)

Each horizontal dash is one home with geometric means for each flooring type shown as darker black lines and dotted geometric means across all samples for each phthalate metabolite. The shape of the ‘bean’ gives the weight of the distribution from a kernel density estimate. P-values are shown from Mann-Whitney tests.

Table 1

Characteristics of children and mothers (*n*=239)

Child's Age (years) mean (SD)	6.5 (1.7)
Child's Sex (% male)	49
Ethnicity	
African American (%)	33
Dominican (%)	67
Mother's Education	
High school or greater (%)	66
Mother's Marital Status	
Never married (%)	66

Missing: mother's marital status (*n*=1)

Table 2

Summary statistics for concentrations of indoor air phthalates and urinary metabolites (*n*=239)

			Percentile						
Phthalate diester	**Phthalate metabolite**	**Percent > LOD[a]**	**Min**	**25%**	**50%**	**75%**	**95%**	**Max**	**GM (95% CI)**
(ng/m^3)									
BBzP		100%	2	8	12	32	191	464	17 (15 to 19)
DEHP		100%	28	62	84	123	241	353	89 (83 to 95)
	(ng/ml)								
	MBzP	100%	0.4	12	25	54	170	1404	26 (22 to 30)
	MEHHP	100%	2	23	50	110	284	1690	50 (43 to 58)

LOD, limit of detection; GM, geometric mean

[a] *n*=41 air samples were below the lowest standard for BBzP leading to imprecise quantitation