

PVC flooring at home and development of asthma among young children in Sweden, a 10-year follow-up

Abstract The incidence of asthma and allergy has increased throughout the developed world over the past decades. During the same period of time, the use of industrial chemicals such as phthalates, commonly used as plasticizers in polyvinylchloride (PVC) flooring material, has increased. The aim of this study was to investigate whether PVC flooring in the home of children in the age of 1–5 years is associated with the development of asthma in 5- and 10-year follow-up investigations ($n = 3228$). Dampness in Buildings and Health Study (DBH Study) commenced in 2000 in Värmland, Sweden. The current analyses included subjects who answered all baseline and follow-up questionnaires. Logistic regression analyses were applied to questionnaire results. Children who had PVC floorings in the bedroom at baseline were more likely to develop doctor-diagnosed asthma during the following 10-year period when compared with children living without. There were indications that PVC flooring in the parents' bedrooms was strongly associated with the new cases of doctor-diagnosed asthma when compared with child's bedroom. Our results suggest that PVC flooring exposure during pregnancy could be a critical period in the development of asthma in children at a later time; prenatal exposure and measurements of phthalate metabolites should be included in the future.

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Key words: Allergy; Asthma; Children; Dampness in Buildings and Health Study; Endocrine-disrupting chemicals; Incidence; Longitudinal; Phthalates; Polyvinylchloride flooring.

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Received for review 19 March 2013. Accepted for publication 2 October 2013

Practical Implications

This study has found that PVC flooring material in early life was related to incidence of asthma during the following 10 years when compared with other flooring materials and especially when comparing with wood flooring type. The study has further indicated that PVC flooring in the parents' bedroom (proxy for prenatal exposure) was more associated with the development of asthma than PVC in the child's bedroom was. Our results suggest that PVC flooring exposure during pregnancy could be a critical period in the development of asthma in children at a later time. In future prospective cohort study, prenatal exposure and measurements of phthalate metabolites should be included.

Introduction

There are approximately 235 million people who are suffering from asthma globally, and it is the most common chronic disease among children (WHO 2011). The incidence of asthma and allergy has increased throughout the developed world over the past decades even if there are indications of a plateau in recent years (Lotvall et al., 2009). During the same period of time, the use of industrial chemicals such as phthalates has dramatically increased, a group of semi-volatile synthetic chemicals also known as endocrine-disrupting chemicals (EDCs), which have many industrial and

consumer uses, such as adhesives, lubricants, lacquers, solvents for inks and paints, building materials, household furnishings, food packaging, clothing, cosmetics, personal care products, pharmaceuticals, medical devices, dentures, waxes, and cleaning materials (Schettler, 2006; Xu et al., 2009). Phthalates are also commonly used as plasticizers in polyvinylchloride (PVC) materials such as flooring materials. Its usage has increased due to its flexibility and transparent properties (Rakkestad et al., 2007).

Endocrine-disrupting chemicals can mimic the function of our endogenously produced hormones or interfere with their production or with hormone receptors,

and thereby interact with the endocrine system by either overstimulating or attenuating its delicately regulated proper function, thus disrupting necessary biological processes from conception to old age (EPA, 2007). With this interesting and potentially powerful property of EDCs, many researchers have conducted studies on human health effects of the exposures to these EDCs.

People spend approximately 90% of their time indoors (Leech et al., 2002); the indoor environment has been considered as an important phthalate exposure background. Phthalates do not form chemical bonding in plastics and thus leach out from the material/products to the environment; hence, a majority of people are being exposed constantly (Fromme et al., 2004; Rakkestad et al., 2007). Diethylhexyl phthalate (DEHP) and butylbenzyl phthalate (BBzP) have been found in indoor dust samples that were collected within studies from different countries (Becker et al., 2004; Fromme et al., 2004; Langer et al., 2013; Oie et al., 1997; Rudel et al., 2003). Bornehag et al. (2005) explored indoor phthalate levels in 390 homes in Sweden and indicated a statistically significant positive correlation between the PVC flooring covered area and the indoor DEHP and BBzP levels in dust samples, which means such flooring material is an important source for these two compounds indoor. Carlstedt et al. (2013) did also show that PVC flooring in the bedroom of the child was associated with a higher level of BBzP metabolites in Swedish infants. These findings have specifically emphasized the increased risk of phthalates exposures in children. The ingestion of household dust for children has been shown to be more than double the amount of adults' ingestion (EPA, 2007). Many researchers have hypothesized that the reason for this relationship was due to their proximity to the floor and also the frequent hands-to-mouth behavior of young children. Guo and Kannan (2011) compared the daily intake level of several phthalate esters from indoor dust between cities in China and cities in the United States and found that toddlers consistently had the highest intake levels for all examined phthalate esters, diethyl phthalate (DEP), dibutyl phthalate (DBP), BBzP, and DEHP across all age groups (infants, toddlers, children, teenagers, and adults). There is a growing body of literatures showing an association between phthalates and symptoms in the airways (wheezing, asthma) and in the skin (eczema) that can be of allergic (IgE-mediated) or non-allergic origin in children, but most of the epidemiological studies are of a cross-sectional design (Bornehag and Nanberg, 2010; Bornehag et al., 2004b; Jaakkola and Knight, 2008). Another previous report on a 5-year questionnaire follow-up study showed a relationship between PVC flooring in childhood and the development of asthma in children (Larsson et al., 2010).

The aim of this study was to investigate whether PVC flooring in the homes of children in the age of 1–5 years is associated with the development of asthma in a 5-year and a 10-year follow-up investigation by using the Dampness in Buildings and Health (DBH) Study results.

Material and methods

The purpose of the DBH Study was to examine the role of indoor environmental factors and lifestyles in early life for chronic health problems such as asthma and allergies later on in Värmland, Sweden. The DBH Study consists so far of four different phases.

- DBH I was conducted in 2000 in Värmland; postal questionnaires were sent to all children (14 077) aged 1–5 years, where 79% ($n = 10\,851$) responded. The questionnaire covered a broad spectrum of issues including lifestyle, environmental exposures with much focus on the characteristics of the home, health and background information about the family and their child (Bornehag et al., 2004a). Asthma and allergy questions were the same as in the ISAAC concept.
- DBH II was a nested cross-sectional, case-control study with a subset of the DBH I cohort (Bornehag et al., 2005). This phase was not included in the current analysis.
- DBH III was a 5-year follow-up study conducted in 2005. Here, we were able to study the incidence of allergic disease and factors affecting such incidence. Diagnosis information such as asthma, pneumonia, rhinitis, neurodevelopmental disorder along with building characteristics was collected. DBH III questionnaires were only sent to the three youngest age groups (1–3 years) in DBH I who were 6–8 years old in 2005; 73% ($n = 5481$) responded to the DBH III questionnaires (Larsson et al., 2010).
- DBH IV was a 10-year follow-up conducted in 2010. The study was aimed toward all children in Värmland aged 11–15 years ($n = 15\,043$) and their parents. The overall purpose of this follow-up was to identify young people's health status and their living conditions, as well as to provide a better understanding of indoor environment in relation to the development of chronic disease in children in Värmland. Parental reports of allergic symptoms and doctor-diagnosed asthma ('Has your child been diagnosed with asthma by a doctor?') were collected. Of the invited subjects, 51% ($n = 7694$) responded to the DBH IV questionnaires. There were two different types of DBH IV questionnaire, long and short, which were delivered to subjects with two different methods, paper-based questionnaires and web-based questionnaires. The short questionnaire was reduced version of the long questionnaire. DBH IV long questionnaires were first delivered via web-based

questionnaire method, and 4423 subjects responded; the same questionnaires were then delivered to subjects via paper method, and 1284 subjects responded. In order to increase the response rate, a shorter version of the DBH IV long questionnaire was delivered to subjects via paper method, and 2181 subjects responded.

The current statistical analyses included 3228 children where data were available from all three datasets: the baseline (DBH I), the 5-year follow-up (DBH III), and the 10-year follow-up (DBH IV; Figure 1 and Table 1). The study was approved by the medical ethics committee at Örebro University, Sweden, (DBH I) and Uppsala University (DBH III and DBH IV).

Statistical analyses

Associations between PVC floorings and incidence of doctor-diagnosed asthma were analyzed using binomial logistic regression, where all other floorings (Linoleum, wood, tile, carpet, cork) and wood flooring were used as reference flooring type individually, with 0.05 significant levels. Crude odds ratio (OR) and adjusted odds ratio (aOR) were used to interpret the results. Statistical analyses were conducted using SPSS for Windows (V.19.0; IBM Corp, Armonk, NY, USA).

The variables we adjusted for were age, sex of the subject, allergies (asthma, eczema, and/or rhinitis) in the family (father, mother, and siblings), smoking in the family (father, mother, siblings, and others), single-parent households where child live with one adult only, housing types (multifamily house, single-family house) which were collected at the baseline (DBH I).

The incidence of parent-reported, doctor-diagnosed asthma (at 5-year and at 10-year follow-up) was

calculated by excluding those subjects whose parents reported 'doctor-diagnosed asthma' and/or 'wheezing ever' at the baseline questionnaire. In the first model (A), we estimated the risk with PVC for incidence of asthma at the 5-year follow-up; in the second model (B), we estimated the risk for asthma at the 10-year follow-up; and in the third model (C), we estimated the risk for new asthma cases after the 5-year follow-up where the cases (asthma and wheezing) at the 5-year follow-up were excluded.

Of 3228 subjects that were available, there were 2389 subjects who had no doctor-diagnosed asthma and 'wheezing ever' at the baseline (DBH I) and 2080 subjects who had no doctor-diagnosed asthma and 'wheezing ever' at both baseline (DBH I) and 5-year follow-up (DBH III).

Results

Cohort characteristics

Several changes (Table 1) were found in terms of the characteristics of the studied families and their homes during the 10-year investigation period. Existence of PVC flooring in both children's and parents' bedrooms was decreased by approximately 12–15%, whereas the existence of wood flooring was increased by approximately 13%. There is also a decreasing trend in the number of smokers in the family during the 10-year follow-up period: Mother smoking decreased by approximately 6%, whereas father smoking decreased approximately by 1%. However, the percentage of single-parent households where child lived with only one adult was increased from 9.6% to 26.2%. During this 10-year period, the percentage of people who were affected by asthma and allergy in the family was stable around approximately 55%.

Asthma in children

During the 5-year follow-up period, between answering the baseline questionnaire and the 5-year follow-up questionnaire, 77 children developed doctor-diagnosed asthma, which corresponded to an annual asthma incidence rate of 6/1000/year. During the 10-year follow-up period, between answering the baseline questionnaire and the 10-year follow-up questionnaire, 145 children developed doctor-diagnosed asthma, which corresponded to an annual asthma incidence rate of 13/1000/year; while we exclude the asthma and wheezing cases from 5-year follow-up (DBH III), there were 52 children developed doctor-diagnosed asthma during the period between the 5-year and the 10-year follow-up, which corresponded to an annual asthma incidence rate of 5/1000/year.

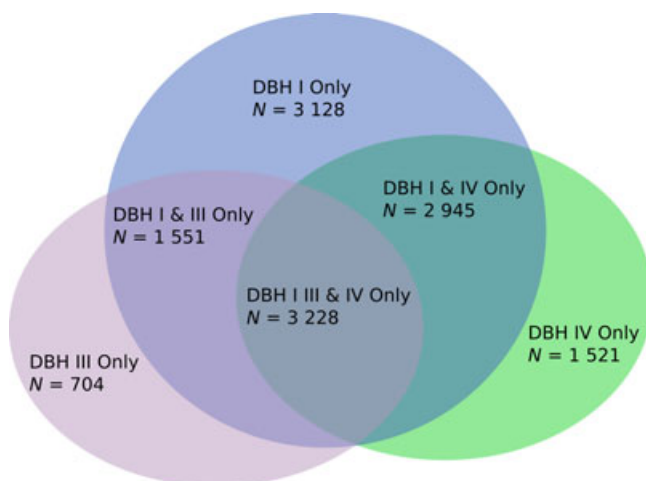


Fig. 1 Dampness in Buildings and Health (DBH) Cohorts' layout (*n* represents the number of responses in each step of the DBH Study)

Table 1 Description of Dampness in Buildings and Health cohorts, their families, and their homes

Factors	Frequency <i>n</i> (%)			
	DBH I Baseline (<i>n</i> = 10 851)	DBH III 2005 follow-up (<i>n</i> = 5482)	DBH IV 2010 follow-up (<i>n</i> = 7694)	DBH I, III, & IV (<i>n</i> = 3228)
Sex				
Female	5410 (49.9%)	2387 (50%)	3812 (49.5%)	1604 (49.7%)
Male	5441 (50.1%)	2391 (50%)	3882 (50.5%)	1624 (50.3%)
Age				
1	2017 (18.6%)	1556 (32.6%)	1475 (19.2%)	1052 (32.6%)
2	2003 (18.5%)	1568 (32.8%)	1462 (19%)	1085 (33.6%)
3	2115 (19.5%)	1654 (34.6%)	1514 (19.7%)	1091 (33.8%)
4	2292 (21.1%)	—	1602 (20.8%)	—
5	2424 (22.3%)	—	1641 (21.3%)	—
Type of dwelling				
Single family	7783 (72.5%)	4223 (78.5%)	4109 (76.9%)	1984 (80.9%)
Attached or semi-attached	942 (8.8%)	429 (8%)	458 (8.6%)	210 (8.6%)
Flat, apartment in multifamily	1847 (17.2%)	658 (12.2%)	642 (12%)	203 (8.3%)
Other	167 (1.6%)	68 (1.3%)	132 (2.5%)	55 (2.2%)
Smokers in the family				
Mother	1910 (17.6%)	737 (13.5%)	637 (11.9%)	246 (10.1%)
Father	1296 (11.9%)	488 (9%)	584 (11%)	218 (9.3%)
Asthma or allergic problems in the family				
Yes	5813 (54.2%)	—	4133 (55.1%)	1805 (57%)
No	4916 (45.8%)	—	3366 (44.9%)	1364 (43%)
Flooring material in child's bedroom				
PVC	4347 (49.8%)	1901 (39.6%)	1296 (34.4%)	576 (32.9%)
Wood	3452 (39.5%)	2496 (52%)	2192 (58.2%)	1051 (60.1%)
Linoleum	934 (10.7%)	405 (8.4%)	279 (7.4%)	122 (7%)
Flooring material in mother's bedroom				
PVC	3677 (42.1%)	1577 (32.8%)	1217 (30.7%)	542 (29.7%)
Wood	4299 (49.2%)	2856 (59.5%)	2501 (63.1%)	1186 (65.1%)
Linoleum	803 (9.2%)	341 (7.1%)	250 (6.3%)	95 (5.2%)
Single parenthood				
Yes	1025 (9.6%)	1154 (21.2%)	1425 (26.2%)	512 (20.5%)
No	9653 (90.4%)	4293 (78.8%)	4014 (73.8%)	1980 (79.5%)

PVC flooring and the incidence of asthma

In the 5-year follow-up crude analysis (Table 2: Model A), we could find that PVC in childhood was associated with the development of doctor-diagnosed asthma, with a slight difference between the PVC flooring in the children's bedroom (OR 1.49; 95% CI 0.92–2.42) and parents' bedroom (OR 1.75; 95% CI 1.08–2.83) at the baseline. Once we adjusted for potential confounding variables, the ORs and the differences between the bedrooms remained the same.

In the 10-year follow-up crude analysis (Table 2: Model B), the same pattern between the incidence of doctor-diagnosed asthma and whether the PVC flooring was in children's bedroom (OR 1.41; 95% CI 0.99–2.01) or parents' bedroom (OR 1.96; 95% CI 1.38–2.79) at the baseline remained. Once we adjusted for potential confounding variables, the differences became less significant between the PVC flooring in children's bedroom (aOR 1.54; 95% CI 1.06–2.23) and parents' bedroom (aOR 2.04; 95% CI 1.41–2.94) at the baseline.

In order to confirm that our results in the 10-year follow-up were not just a repeat of the 5-year

follow-up data (Model A), we excluded the asthma cases that were identified in the 5-year follow-up (Table 2: Model C). The association between parents' bedroom with PVC flooring in childhood- and doctor-diagnosed asthma that were diagnosed after the 5-year follow-up went up slightly (aOR 2.23; 95% CI 1.22–4.08), whereas for child's bedroom, it remained as borderline significance (aOR 1.54; 95% CI 1.06–2.23).

Because people might have difficulties in identifying between PVC flooring and linoleum flooring, we also looked into PVC flooring in early life against wood flooring only (where people in general are good in judging wood material); a clearer pattern was found for both 10-year follow-up (Model B) and 10-year follow-up excluding 5-year follow-up asthma cases (Model C; Table 2). In the 10-year follow-up, PVC flooring in the parents' bedroom was statistically significantly associated with the incidence of doctor-diagnosed asthma (aOR 1.90; 95% CI 1.29–2.81). In contrast, this association was weaker for exposure in the child's bedroom for both crude (OR 1.24; 95% CI 0.86–1.80) and adjusted models (aOR 1.37; 95% CI 0.92–2.04).

Table 2 Association between doctor-diagnosed asthma at follow-ups (5 and 10 years) and PVC flooring in childhood 5 or 10 years earlier, extracted by rooms and expressed as crude and adjusted odds ratio

Model	Incidence of doctor-diagnosed asthma, crude OR (95% CI)		Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI)	
	Child's bedroom	Parents' bedroom	Child's bedroom	Parents' bedroom
PVC vs. other flooring material				
A – 5-year follow-up	1.49 (0.92–2.42)	1.75 (1.08–2.83)	1.50 (0.91–2.47)	1.71 (1.05–2.80)
B – 10-year follow-up	1.41 (0.99–2.01)	1.96 (1.38–2.79)	1.54 (1.06–2.23)	2.04 (1.41–2.94)
C – 10-year follow-up where asthma cases 2005 excluded	1.41 (0.99–2.01)	2.05 (1.15–3.65)	1.54 (1.06–2.23)	2.23 (1.22–4.08)
PVC vs. wood flooring material				
A – 5-year follow-up	1.34 (0.81–2.24)	1.63 (0.98–2.69)	1.35 (0.79–2.31)	1.60 (0.95–2.70)
B – 10-year follow-up	1.24 (0.86–1.80)	1.80 (1.25–2.61)	1.37 (0.92–2.04)	1.90 (1.29–2.81)
C – 10-year follow-up where asthma cases 2005 excluded	1.24 (0.86–1.80)	1.95 (1.06–3.59)	1.37 (0.92–2.04)	2.18 (1.14–4.16)

CI, confidence interval; OR, odds ratio; PVC, polyvinylchloride.

^aAdjustment made for sex, age, type of dwelling, smokers in the family, asthma or allergic problems in the family, flooring materials in the bedrooms (parents' and children's), single-parent household.

Bold values indicate significant level at 0.05.

Table 3 Association between doctor-diagnosed asthma and PVC flooring in parents' bedroom, stratified by relocation and expressed as adjusted odds ratio

Model	Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI) moved		Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI) did not move	
	N	Parents' bedroom	N	Parents' bedroom
PVC vs. other flooring material				
A – 5-year follow-up	713	1.43 (0.59–3.47)	1483	1.93 (1.06–3.51)
B – 10-year follow-up	692	1.81 (0.92–3.57)	1431	2.23 (1.43–3.49)
C – 10-year follow-up where asthma cases 2005 excluded	609	2.13 (0.71–6.36)	1237	2.52 (1.18–5.41)
PVC vs. wood flooring material				
A – 5-year follow-up	636	1.46 (0.56–3.82)	1324	1.70 (0.90–3.19)
B – 10-year follow-up	619	2.24 (1.03–4.85)	1275	1.89 (1.19–3.00)
C – 10-year follow-up where asthma cases 2005 excluded	547	3.66 (0.93–14.41)	1096	2.05 (0.95–4.43)

CI, confidence interval; OR, odds ratio; PVC, polyvinylchloride.

^aAdjustment made for sex, age, type of dwelling, smokers in the family, asthma or allergic problems in the family, flooring materials in the bedrooms (parents' and children's), single-parent household.

Bold values indicate significant level at 0.05.

PVC flooring and asthma by relocation

In order to identify the exposure period, we also stratified models (Table 3) by whether the child and family had moved to another location since birth but prior to the time of answering the DBH I baseline questionnaires. For the children who lived in the same location since birth at the baseline investigation (DBH I), in the case of comparing between PVC flooring and other flooring types, a clearer pattern was found for both 10-year follow-up (Model B: aOR 2.23; 95% CI 1.43–3.49) and 10-year follow-up excluding 5-year follow-up asthma cases (Model C: aOR 2.52; 95% CI 1.18–5.41; Table 3), whereas the same association was weaker when the family had moved since birth. In the case of comparing between PVC flooring and wood flooring type, the association that was found in the PVC vs. other flooring types disappeared (Table 3).

We also examined whether the association between PVC flooring in the parents' bedroom and incidence of

asthma was related to which room the child slept in during early life. In these stratified analyses, we could not find any difference depending on location (Table 4).

Asthma and number of rooms with PVC as flooring material

For the children's family who had both parents' bedroom and child's bedroom with PVC flooring at the baseline investigation (DBH I), a clearer pattern was found for both 10-year follow-up (aOR 2.08; 95% CI 1.37–3.15) and 10-year follow-up excluding 5-year follow-up asthma cases (aOR 2.44; 95% CI 1.30–4.57). We also examined for subjects who only had one room with PVC floorings, whether it makes any differences in the parents' bedrooms or the child's bedroom with PVC floorings. In this stratified analysis, we found that for the 10-year follow-up model, PVC flooring in parents' bedroom only (aOR 2.23; 95% CI 1.11–4.47) was more associated with doctor-diagnosed asthma than

Table 4 Association between doctor-diagnosed asthma and PVC flooring in parents' bedroom, stratified by sleeping location and expressed as adjusted odds ratio

Model	Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI) not sleep in parents' bedroom		Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI) sleep in parents' bedroom	
	N	Parents' bedroom	N	Parents' bedroom
PVC vs. other flooring material				
A – 5-year follow-up	1255	2.01 (0.99–4.09)	942	1.06 (0.50–2.25)
B – 10-year follow-up	1213	1.91 (1.15–3.16)	912	2.02 (1.16–3.52)
C – 10-year follow-up where asthma cases 2005 excluded	1056	2.20 (0.96–5.00)	791	2.62 (1.05–6.52)
PVC vs. wood flooring material				
A – 5-year follow-up	1145	2.04 (0.96–4.36)	818	0.95 (0.43–2.10)
B – 10-year follow-up	1107	1.83 (1.08–3.09)	791	1.85 (1.01–3.36)
C – 10-year follow-up where asthma cases 2005 excluded	961	2.08 (0.89–4.89)	684	2.67 (0.97–7.32)

CI, confidence interval; OR, odds ratio; PVC, polyvinylchloride.

^aAdjustment made for sex, age, type of dwelling, smokers in the family, asthma or allergic problems in the family, flooring materials in the bedrooms (parents' and children's), single-parent household.

Bold values indicate significant level at 0.05.

Table 5 Association between doctor-diagnosed asthma and combinations of PVC flooring in the child's and parents' bedroom, expressed as adjusted odds ratio

Model	Incidence of doctor-diagnosed asthma, adjusted OR ^a (95% CI)			
	Child BR: No PVC, Parent BR: No PVC, (N = 1221) REF	Child BR: No PVC, Parent BR: Yes PVC, (N = 164)	Child BR: Yes PVC, Parent BR: No PVC, (N = 359)	Child BR: Yes PVC, Parent BR: Yes PVC, (N = 1157)
A – 5-year follow-up	1.00 (–)	2.03 (0.79–5.19)	1.15 (0.48–2.75)	1.76 (1.01–3.09)
B – 10-year follow-up	1.00 (–)	2.23 (1.11–4.47)	0.82 (0.39–1.72)	2.08 (1.37–3.15)
C – 10-year follow-up where asthma cases 2005 excluded	1.00 (–)	1.36 (0.37–4.92)	0.22 (0.30–4.57)	2.44 (1.30–4.57)

CI, confidence interval; BR, bedroom; OR, odds ratio; PVC, polyvinylchloride; REF, reference.

^aAdjustment made for sex, age, type of dwelling, smokers in the family, asthma or allergic problems in the family, flooring materials in the bedrooms (parents' and children's), single-parent household.

Bold values indicate significant level at 0.05.

PVC flooring in child's bedroom only (aOR 0.82; 95% CI 0.39–1.72; Table 5).

Discussion

Within this cohort, we found that annual asthma incidence rate ranged from 5/1000/year to 13/1000/year, which was comparable to what Broms et al. (2012) reported annual asthma incidence rate of 6/1000/year to 12/1000/year, a study that was based on a large sample of preschool children (aged 1–5) covering all of Sweden.

In this analysis, children who lived in homes with PVC floorings in the bedroom when they were 1–5 years of age were more likely to develop doctor-diagnosed asthma during the following 10-year period when compared with children living in homes without PVC flooring in the bedroom. Furthermore, there were indications that PVC flooring in the parents' bedrooms were strongly associated with the new cases of doctor-diagnosed asthma when compared with PVC flooring in the child's bedroom. We also found that the risk with PVC flooring was slightly stronger for late-onset

asthma, that is, asthma developed after the 5-year follow-up investigation. Finally, these associations were not changed regardless of whether the child slept in the parents' bedroom or not. We also applied the same analysis to the dataset where subjects only answered DBH I and DBH IV, and the same pattern was found.

Once we excluded the asthma cases that were identified in the 2005 follow-up, the associations were still significant and became stronger. This is an indication that late-onset asthma in children may be strongly associated with the exposures of PVC flooring early in life. The reason for such differences in associations is not fully clear. One may speculate that children that later on (after the baseline investigation) developed asthma did need more care from the parents during their childhood and therefore spend more time in the parents' bedroom. However, we believe that only when a child has developed asthma and perhaps been diagnosed with asthma, they tend to need more care from parents at nighttime due to the possibility of worsening asthma symptoms during sleep. We also took into consideration that children with early wheezing may need more care; however, with this dataset, we excluded

children who had wheezing at the baseline (DBH I). So there is no reason to believe that children need more care prior to asthma diagnosis during infancy, and therefore, we do not believe that children that later on will be diagnosed with asthma did sleep more in the parents' bedroom during childhood.

The current findings are partly in line with the results from an earlier report from the same study where Larsson et al. (2010) found that PVC flooring in the bedrooms of children at the age of 1–5 years was associated with the incidence of asthma at the 5-year follow-up. However, Larsson et al. (2010) did not see any difference in the aOR between child's (aOR 1.52; 95% CI 0.99–2.35) and parents' bedroom (aOR 1.46; 95% CI 0.96–2.23) as we can see in the current analyses, which we cannot explain. The current result indicates that PVC flooring (in the parents' bedroom) is more related to late-onset asthma.

Another interesting finding – indicating that the parents' bedroom is more important – was when the location of PVC flooring was introduced into the models. Subjects who had PVC flooring in parents' bedrooms, but not in child's bedroom at the baseline (DBH I), had a stronger association compared to subjects who had PVC flooring in child's bedrooms, but not in parents' bedroom, at the baseline (DBH I), with doctor-diagnosed asthma. Our result shows under the mask of the dose-response relationship between the number of rooms and the development doctor-diagnosed asthma, the location of PVC flooring is also an important determining factor.

Furthermore, when we stratified the model by sleeping locations, we did not observe a difference in terms of whether children sleep with parents or not, which is an indication that postnatal environment does not play as an important role as prenatal environment in this cohort.

Another possible explanation of this association with parents' bedrooms could be that the flooring in the parents' bedroom at the time for the baseline questionnaire represents the situation during the pregnancy period. This could then indicate the exposure situation for the pregnant women. For the children who at baseline had lived in the same location since birth, PVC flooring in the parents' bedroom was significantly associated with having doctor-diagnosed asthma, whereas this association was not seen in the child's bedroom.

There have been hypotheses focusing on prenatal exposure of importance for the development of different chronic diseases such as asthma and allergy (Meeker et al., 2009; Tellez-Rojo et al., 2013; Wolff et al., 2008; Ye et al., 2008). Prenatal exposure for EDCs – which can interfere with our endocrine systems – and asthma in children has not been well studied but data are growing. Just et al. (2012) found more than 99% of the samples with detectable level of MBzP in the urine samples which were collected during the third

trimester of pregnancy, where MBzP was found positively associated with any report of children with eczema by 24 months of age (RR = 1.52; 95% CI 1.21–1.91).

One of the potential confounding factors one may speculate regarding our findings is socioeconomic status (SES) of subjects. Koo et al. (2002) found that people with household income level below \$1500 prior to sample collections and with only high school education had higher BBzP and DEHP exposure, by using the third National Health and Nutritional Examination Survey (NHANES III). In the present report, we did not have information on subjects' household income; we therefore used proxies for lower SES such as living in a multifamily dwelling and smoking among parents. Smoking seems not to be a confounder because the pattern of associations could be found among non-smokers, which is the largest group (smokers are around 10% of the population with limited statistical power), and we could find a higher adjusted OR for the parents' bedroom compared with the child's bedroom also in the non-smoking group.

Limitations

We acknowledge several limitations within these analyses; doctor-diagnosed asthma was assessed through questionnaires and therefore subject to a lack of standardization and recall bias. However, parental reports on health outcomes such as doctor-diagnosed asthma have been shown valid in the previous findings (Hederos et al., 2007). This analysis does not subject to report bias on flooring material, since the PVC information was collected in 2000 and at the time an association with asthma had not been well studied, and the data on asthma diagnosis were collected 5 or 10 years later, which should not interfere with subjects' answer regarding the usage of PVC flooring. Another problem is that people in general are bad in judging PVC and linoleum flooring, however good in judging and reporting wood flooring (Bornehag et al., 2006). We did try to control for this by using only wood flooring as reference, and the same pattern in associations was found. Lack of prenatal exposure information and lower response rate for DBH IV are also limitations of the study; however, lower response rate did not seem to have any impact on, for example, asthma and allergy problems in the family of the DBH IV cohort, when compared to DBH I, and DBH III (Table 1). Another limitation of this analysis is the lack of information on the exact composition of the PVC flooring. Based on the products registry provided by KEMI (Swedish Chemical Agency), there has been a reduction in the production of DEHP, which is largely being replaced by diisononyl (DiNP) phthalate; however, this analysis is looking into the exposure in the past 10 years, prior to the beginning of the reduction in DEHP production.

Conclusions

This study has found that PVC flooring material in early life was related to incidence of asthma during the following 10 years when compared with other flooring materials and especially when comparing with wood flooring type. The study has further indicated that PVC flooring in the parents' bedroom was more associated with the development of asthma than PVC flooring in the child's bedroom was. A reason for such a difference in associations could be that the flooring material in the parents' bedroom is a proxy for the exposure situation during pregnancy, while the flooring material in the child's bedroom is more describing the situation during the infancy period.

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Our results suggest that PVC flooring exposure during pregnancy could be a critical period in the development of asthma in children at a later time. In future prospective cohort study, prenatal exposure and measurements of phthalate metabolites should be included.

Acknowledgements

The study was funded by grants from the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), Swedish Asthma and Allergy Association's Research Foundation, the Swedish Foundation for Health Care Sciences and Allergy Research, and the County Council of Värmland. We also thank all the participating families.

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