

Indoor allergen levels and other environmental risk factors for sensitization in Estonian homes

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The prevalence of allergic disease is low in Eastern Europe for reasons that are poorly understood. Our study aimed to investigate the levels of exposure to indoor allergens and living conditions among Estonian infants in relation to sensitization. Dust samples were collected during four winter months in 1993/94 from the homes of 197 infants participating in a prospective study of sensitization. Information about living conditions was collected through a home visit and interviewing the mothers when the children were 6 weeks old. Three dust samples were collected from each home; i.e., from the infant's mattress, bedroom floor, and living-room carpet. The levels of allergens were determined by ELISA with monoclonal antibodies. The highest allergen level in a home was regarded as the peak value. The peak geometric mean values ($\pm$ SD) of Der p 1 and Der f 1 were 0.3 (0.07–1.4) μ g/g dust, of Can f 1, 0.86 (0.23–3.12) μ g/g dust, and of Fel d 1, 0.1 (0.01–0.9) μ g/g dust. In 12 homes (9%), the peak value of house-dust mite (HDM) allergens exceeded 2 μ g/g dust, with Der p 1 as the dominating allergen. Multivariate analyses indicated that high levels of HDM allergens were more common in apartments that were on the ground floor or first floor, that were heated with stoves, and/or that had a dampness problem. The mean allergen levels at home were similar in children sensitized to HDM ($n=17$, 0.29 vs 0.3 μ g/g dust), dog ($n=5$, 0.55 vs 1.06 μ g/g dust, and cat ($n=18$, 0.21 vs 0.09 μ g/g dust) and in children who were not sensitized to these allergens. Most of the sensitized children were exposed to relatively low allergen levels at home; i.e., below 1 μ g/g dust. This level was exceeded in the homes of 4/17 mite-, 5/18 cat-, and 0/5 dog-sensitized children. The similar levels of the major indoor allergens in Estonia and in Scandinavia indicate that the large differences in atopy prevalence among children and young adults in the two regions are not due to differences in allergen exposure. No allergen threshold level for sensitization was identified.

Furred pet animals and house-dust mites (HDM) produce the major indoor allergens (1–5). Various environmental factors, such as dampness of the home, indoor temperature, living habits, age of the house, and season, can all influence the levels of mite allergens in house dust (6–8). Recent studies have suggested that the levels of HDM allergens may have increased in countries with a temperate climate, as a result of increased temperature and humidity due to changes in the indoor climate (9–11).

Comparative epidemiologic investigations carried out among schoolchildren (12) and young

adults (13) show that atopic sensitization to pets, birch, and grass is less common in Estonia than in Sweden. However, sensitization to HDM was equally common in the two countries, possibly indicating that the levels of this allergen are high in Estonia although its climate is like that of Sweden.

There are major differences in the living conditions in Estonia and Sweden. In Estonia, most people live in multifamily houses in rather small and crowded apartments. The houses are made from bricks or from concrete blocks, and they are

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heated by water radiators. The houses have good natural ventilation due to low building standards, and mechanical ventilation systems are absent.

The present study aimed to analyze the levels of major indoor allergens, i.e., HDM, cat, and dog allergens, in Estonian homes and to assess some indoor environmental factors that could influence the levels of these allergens. The study was done as part of a prospective study of sensitization and development of allergic diseases during early childhood.

Material and methods

Subjects and environmental data

The study comprised 298 infants who were born at Tartu Women's Clinic (Tartu, Estonia) from November 1993 to February 1994 and whose families had agreed to participate in a prospective study investigating the development of allergic disease over the first years of life in relation to environmental conditions (14).

When the infants were 4–6 weeks old, i.e., November 1993–March 1994, two pediatricians (K. J. and M.V.) visited 197 homes in Tartu. For practical reasons, dust samples could not be collected from homes outside Tartu. The mothers were questioned about living conditions, i.e., type of home (apartment/private house), number of persons living together, living area, floor material, type of heating and cooking, indoor temperature during the winter, contact with furred animals and birds, presence of insects, signs of dampness, smoking habits of family members, and cleaning habits in the home. The indices of damp housing conditions included persistent presence of visible damp spots in the home on either the walls, floor, or ceiling; visible mold growth in the home; water condensation on double-pane windows during the winter; and a foul smell recognized by visitors.

The outdoor temperature and humidity data were collected from the Tartu aerometeorologic station of the Estonian Meteorologic and Hydrologic Institute. The mean temperature was -5.4°C , absolute humidity 3.9 g/m^3 , and relative humidity 86% during the sampling period. Special measurements were not done to register room temperature. The parents recorded the normal indoor temperature with an ordinary thermometer.

Collection and analysis of house-dust samples

Three dust samples were collected by two of us (K. J., M.V.), with vacuum cleaners (Electrolux, Dolphin with microfilter) connected to a special dust collector device containing a filter (pore size, $6\text{ }\mu\text{m}$)

(ALK, Hørsholm, Denmark). Bedroom dust was collected by vacuum-cleaning 2 m^2 of the floor area for 1 min per m^2 , the infant's mattress (1 m^2 area for 2 min), and 2 m^2 of the living-room carpet for 2 min per m^2 . The dust samples were stored at -20°C until processed. The filter boxes containing dust samples were opened, and the amount of dust weighed. Aqueous extracts of the dust samples were prepared with an extraction ratio of 1:10 (w/v) or 1:20 (if the amount of dust was less than 30 mg) by dissolving the dust sample in phosphate-buffered saline (PBS) (pH 7.6) under constant rotation at 4°C overnight. The solution was clarified by centrifugation twice at 800 g (average) for a total of 20 min. To avoid repeated freezing and thawing, the extracts were stored frozen at -20°C in separate aliquots until analyzed. In all, 469 dust samples from 189 homes were available for analysis.

The levels of major mite (Der p 1 and Der f 1), cat (Fel d 1), and dog (Can f 1) allergens in samples from the homes were determined by ELISA, monoclonal antibodies (ALK, Hørsholm, Denmark) being used, as described previously by Munir et al. (8). The detection levels of mite, cat, and dog ELISA were 2, 0.8, and 2 ng/ml, corresponding to 20, 8, and 20 ng/g dust, respectively. For technical reasons, the dust samples from 63 homes could not be analyzed for HDM allergen, from 42 homes for dog allergen, and from 71 homes for cat allergen.

Skin prick tests (SPT) and circulating IgE antibodies

SPT were performed at 12 and/or 24 months of age, as described earlier by us (14). Briefly, standardized allergen extracts of cat, dog, and HDM (*Dermaphagoides pteronyssinus*) (Solu-Prick SQ, ALK, Hørsholm, Denmark) were employed in duplicate on the volar aspects of the forearms, a lancet from ALK being used. Circulating IgE antibodies against mite (*D. pteronyssinus*, *D. farinae*) and cat allergens in blood samples obtained at 6, 12, and 24 months of age were determined by chemiluminescence, according to the recommendations of the manufacturer (Magic Lite, Hørsholm, Denmark), with the high-sensitivity modification. Sensitization to indoor allergens was indicated by a positive SPT; i.e., a mean wheal diameter of $\geq 3\text{ mm}$, and/or IgE antibodies class 1 or higher. SPT were performed in 144 children, and determination of circulating IgE antibodies in 94 of them.

Statistical analyses

Analyses were performed by the statistical package SAS, Version 6.10. Nonparametric methods were

Table 1. Allergen levels (GM $\pm$ SD) in dust samples collected from floors, carpets, and mattresses in homes of Estonian infants

Allergen	Floor ($\mu\text{g/g}$)		Carpet ($\mu\text{g/g}$)		Mattress ($\mu\text{g/g}$)		Peak values ($\mu\text{g/g}$)	
	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)
Der p 1 plus Der f 1	85	0.09 (0.02–0.38)	108	0.10 (0.03–0.4)	96	0.37 (0.09–1.52)	134	0.3 (0.07–1.4)
Can f 1	87	0.39 (0.08–0.19)	150	0.59 (0.14–2.41)	83	0.73 (0.18–3.0)	155	0.86 (0.23–3.12)
Fel d 1	76	0.01 (<0.01–0.13)	118	0.04 (<0.01–0.34)	72	0.11 (0.01–1.01)	126	0.1 (0.01–0.9)

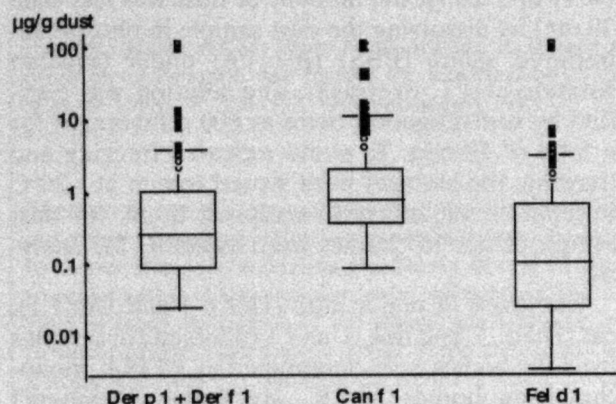


Fig. 1. Highest levels of HDM (Der p 1 plus Der f 1), dog (Can f 1), and cat (Fel d 1) allergen in three samples collected from 189 Estonian homes. Graph shows median and 10th, 25th, 75th, and 90th percentile, as well as individual values above 75th percentile.

analyzed, as the distribution of data was not normal even after logarithmic transformation. The allergen levels in two groups were compared with the Wilcoxon-Mann-Whitney test and Kruskal-Wallis test for more than two groups. Multiple regression analysis was used to assess the influence of certain environmental factors on the allergen levels. The levels of Der p 1 and Der f 1 allergens were combined in the calculation, and the highest allergen level in the home was considered for the statistical analysis. The chi-square test was used to determine the relationship between environmental factors and sensitization.

Ethical considerations

The study was approved by the ethics committee of the Medical Faculty of Tartu University.

Results

Living conditions

Most children (85%) were living in centrally heated apartments (Table 1). The mean size of the apartment was 48 m² (range 9–120 m²), and the mean number of persons living in it was 4 (range 2–11). In 31% of the apartments, three persons were

living; in 36%, four persons; and in 33%, five or more persons. The mean living area was 12 m² per person (range 2.8–40 m²). Gas stoves were used for cooking in 52%, electric stoves in 37%, and wood-burning stoves in 11% of the homes.

The indoor temperature was 18–23°C (mean 21°C) during the winter. There were signs of dampness in 32% of the apartments. A wall-to-wall carpet was present in 18% of the bedrooms and in 18% of the living rooms. Vacuum cleaners were used by 75% of the families.

There was at least one smoker in 64% of the families, and the favorite place for smoking was the kitchen. Only seven persons claimed that they smoked only outdoors.

Fourteen percent of the families had a dog and 10% a cat. Another 5% kept a cat or dog only outside, and 10% of the families had previously had a pet. Three families kept a bird.

Allergen levels and sensitization

HDM allergens were detected in all homes; i.e., in 86% of the samples collected from the floor, in 92% of those collected from a carpet, and in all samples from mattresses. The predominate mite allergen was Der p 1. The mite-allergen levels (Der p 1 and Der f 1) in the homes varied from <0.02 to 11.7 $\mu\text{g/g}$ dust (GM 0.3 $\mu\text{g/g}$). The highest levels were recorded in mattresses, while the levels in floor and carpet samples were similar (Table 1, $P<0.01$). The mite-allergen levels exceeded 0.5 $\mu\text{g/g}$ dust in at least one sample in 36% of the homes; in 21%, the peak level exceeded 1 $\mu\text{g/g}$ and in 9% of the homes, 2 $\mu\text{g/g}$ dust (Fig. 1).

Dog was the major pet allergen and was detected in 99% of the homes. Thus, Can f 1 was detected in 96–99% of the samples from the floor, carpets, and mattresses. The level of Can f 1 exceeded 0.5 $\mu\text{g/g}$ in 63% of the homes in at least one of the samples; in 23%, the level was over 2 $\mu\text{g/g}$.

Cat allergen was detected in 90% of the homes, mostly in the mattresses, where the highest levels were recorded (GM 0.11 $\mu\text{g/g}$) (Table 1). The level of Fel d 1 was over 2 $\mu\text{g/g}$ in 12% of the homes.

Houses more than 25 years old, wooden houses, location of the apartment on the ground floor or the first floor, heating by stoves, an indoor temper-

Table 2. Relationship between environmental factors and mite (Der p 1, Der f 1), dog (Can f 1), and cat (Fel d 1) allergens. Peak values ($\mu\text{g/g}$) in dust samples from 189 homes. In multiple-regression analysis, location on ground floor or first floor (item no. 4), heating system (no. 5), and dampness problems (no. 7) were significantly associated with increased allergen concentrations

Environmental factor	Der p 1 plus Der f 1			Can f 1		Fel d 1	
	%	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)
1) Type of house							
One family	15	27	0.38 (0.06–2.33)	27	1.42 (0.38–5.35)*	23	0.19 (0.01–2.86)
Apartment	85	107	0.26 (0.06–1.17)	128	0.85 (0.21–2.72)	103	0.09 (0.01–0.68)
2) Age of house							
≥ 25 years	36	50	0.44 (0.08–2.49)**	63	1.06 (0.32–3.52)	53	0.11 (0.01–0.81)
<25 years	64	84	0.21 (0.05–0.87)	92	0.73 (0.19–2.83)	73	0.10 (0.01–1.11)
3) Building material							
Wood	22	31	0.55 (0.11–2.9)*	38	1.11 (0.32–3.92)	31	0.13 (0.01–1.46)
Brick	24	34	0.25 (0.05–1.26)	40	0.76 (0.3–1.93)	35	0.10 (0.01–0.94)
Concrete	54	69	0.22 (0.05–0.92)	77	0.79 (0.18–3.42)	60	0.09 (0.01–0.7)
4) Floor							
$\leq$ First	55	71	0.41 (0.1–1.62)**	84	0.88 (0.24–3.24)	71	0.13 (0.01–1.37)
$\geq$ Second	45	56	0.18 (0.04–0.9)	71	0.81 (0.22–2.92)	55	0.07 (0.01–0.43)
5) Heating system							
Wood stove	23	30	0.67 (0.13–3.52)**	38	1.18 (0.35–3.97)	32	0.14 (0.01–1.43)
Central	77	104	0.22 (0.05–0.94)	117	0.89 (0.21–2.84)	94	0.09 (0.01–0.77)
6) Indoor temperature							
$>18^\circ\text{C}$	87	118	0.32 (0.07–1.5)**	137	0.92 (0.26–2.98)	111	0.11 (0.01–0.88)
$\leq 18^\circ\text{C}$	13	16	0.11 (0.03–0.46)	18	0.68 (0.11–4.07)	15	0.09 (<0.01–1.15)
7) Dampness in home							
Yes	32	32	0.51 (0.12–2.17)*	36	0.97 (0.22–4.36)	29	0.11 (0.01–1.16)
No	68	102	0.23 (0.05–1.11)	119	0.89 (0.24–2.81)	97	0.10 (0.01–0.85)
8) Indoor smoking							
Yes	64	84	0.25 (0.05–1.19)	94	1.03 (0.28–3.82)*	76	0.14 (0.01–1.43)*
No	36	50	0.33 (0.07–1.66)	61	0.63 (0.18–2.17)	50	0.07 (0.01–0.41)
9) Dog at home							
Yes	14	22	0.29 (0.06–1.46)	24	5.77 (2.16–15.4)***	19	0.18 (0.02–2.0)
No	86	112	0.28 (0.06–1.34)	131	0.66 (0.22–1.65)	107	0.09 (0.01–0.78)
10) Cat at home							
Yes	10	16	0.28 (0.06–1.25)	16	1.37 (0.35–5.34)	16	2.15 (1.18–3.93)***
No	90	118	0.28 (0.06–1.37)	139	0.87 (0.22–2.88)	110	0.07 (<0.01–0.47)

* $P < 0.05$; ** $P < 0.001$; *** $P < 0.0001$.

Table 3. Allergen levels ($\mu\text{g/g}$) in homes of children sensitized to respective allergens and nonsensitized children. Level of significance (Wilcoxon-Mann-Whitney) is also shown

Allergen	Sensitized		Nonsensitized		<i>P</i>
	<i>n</i>	GM ($\pm$ SD)	<i>n</i>	GM ($\pm$ SD)	
Der p 1 plus					
Der f 1	17	0.29 (0.04–1.94)	95	0.30 (0.06–1.43)	0.89
Can f 1	5	0.55 (0.44–0.69)	125	1.06 (0.27–3.35)	0.25
Fel d 1	18	0.21 (0.04–1.25)	103	0.09 (0.01–0.9)	0.18

ature over 18°C , and signs of dampness were all associated with the presence of HDM allergens (Wilcoxon-Mann-Whitney test and Kruskal-Wallis test). The levels of pet allergens were particularly high in the homes of pet-keepers, and there was a

positive correlation between the level of pet allergen and smoking habits (Table 2). Multiple-regression analysis, including all the factors listed in Table 2, indicated that high levels of HDM were more common in apartments situated on the ground floor or first floor, those with wood-burning stoves, and/or those with dampness problems.

In all, 46/257 (18%) children were sensitized to indoor allergens, as indicated by a positive SPT and/or circulating IgE antibodies at least once during the first 2 years of life. Thirty-three of them were sensitized to HDM, seven to dog, and 29 to cat allergen.

Dust samples were available for analysis from 17 homes of the 33 children who were sensitized to HDM allergen, and in four the level of Der p 1 and Der f 1 exceeded $1 \mu\text{g/g}$ dust (1.5, 4.5, 7.9, and 8.8

$\mu\text{g/g}$, respectively). The mean level was $0.29 \mu\text{g/g}$, as compared to $0.30 \mu\text{g/g}$ in the homes of children not sensitized to HDM (Table 3). Six of the 17 sensitized children were living in wooden houses and six in homes with dampness problems. Sensitization to HDM tended to be more common among children living in homes more than 25 years old ($\chi^2=3.16$; $P>0.05$) and among infants living in apartments on the ground floor or first floor ($\chi^2=2.33$; $P>0.05$), as compared with children living in new houses and on higher floors. There was no relationship between sensitization to HDM and the number of family members, living area, living area per person, or cleaning habits.

Eighteen homes of 29 children sensitized to cat allergen were investigated for Fel d 1 and in five homes, the allergen level exceeded $1 \mu\text{g/g}$ (1.2, 1.9, 1.9, 2.4, and $3.0 \mu\text{g/g}$, respectively). Five of the 29 cat-sensitized children had a cat at home. The Can f 1 levels in the dust samples from five of the homes of the seven children sensitized to dog allergen did not exceed $0.8 \mu\text{g/g}$. None of the dog-sensitized children had a dog at home. The geometric mean levels of Fel d 1 and Can f 1 were similar in the homes of children who were and were not sensitized to the respective allergens (Table 3).

Discussion

The levels of HDM allergens in Estonian homes were similar to those recorded in central Sweden and Norway (7, 8, 15, 16), and the highest mean value in the home was only $0.3 \mu\text{g/g}$ dust. Thus, the levels were considerably lower than in countries or regions with a warmer climate, e.g., The Netherlands (17), England (1–3), Denmark (11), northern Germany (18), and Portugal (19).

The highest levels of HDM were recorded in homes located on the ground floor or on the first floor and in homes heated by stoves and with dampness problems. The levels were also higher in apartments with an indoor temperature over 18°C . Indoor heating in Estonia had been very cheap when the country was part of the Soviet Union. On the other hand, natural ventilation, due to the Soviet building technique, was good. The causes of indoor dampness problems in Estonia and Western Europe are probably different. Thus, in Sweden, dampness problems are related to efficient insulation and poor ventilation (7, 8), while, in Estonia, dampness appears to be more related to leaking roofs and walls and damp cellars.

Cat and dog allergens were as commonly encountered in the Estonian as in the Swedish homes (15), and the mean levels were similar. This may appear surprising, since only 14% of the Estonian families participating in the present study

had a dog and only 10% had a cat at home, as compared to about 50% in Sweden (15). In a previous study, however, we reported that about 50% of Estonian schoolchildren had a pet animal at home (20). Thus, the investigation of homes with an infant did not give the full picture of exposure to pets in Estonia.

The level of cat allergens was several times higher in mattresses than in floor dust or in carpets. Possible reasons include the fact that the families used old mattresses, sometimes borrowed from other families, and inefficient, Soviet-style vacuum cleaners, which sent small particles of dust into the air when used. Furthermore, awareness of allergic diseases is low in Estonia and awareness of indoor allergens virtually absent. This may explain why people often used old mattresses for their newborn infants and why mattresses were rarely cleaned.

The rather low mite-allergen levels among children who were sensitized during the first 2 years of life indicate that the level of allergen needed for sensitization is lower than $2 \mu\text{g/g}$ dust, as this level was exceeded only in three homes. This agrees with a recent report from Sweden (15) and suggests that there are no clear threshold levels below which sensitization does not occur. However, there is a definite correlation between the level of exposure to allergens and sensitization, as recently confirmed in a large prospective study (21).

The prevalence of sensitization to HDM allergens was similar among Estonian and Swedish schoolchildren and young adults (12, 13) and appeared to be even higher among Estonian children during early childhood (14). This is surprising since sensitization to other inhalant allergens is significantly lower in Estonia (13, 20). The relatively high rate of sensitization to HDM, as compared to pets, in Estonia may be related to the high proportion of homes (21%) with mite-allergen levels above $1 \mu\text{g/g}$ dust.

The similar levels of pet allergens in the homes of children who were sensitized and not sensitized to pets also indicate that the level of allergen needed for sensitization is low. Thus, the Can f 1 levels in all the homes of the dog-sensitized children were below $0.8 \mu\text{g/g}$ dust, and the Fel d 1 levels exceeded $1 \mu\text{g/g}$ dust, only in 5/18 homes of cat-sensitized children. These findings support recent reports that sensitization as indicated by positive SPT may occur even after low levels of exposure (15). Furthermore, recent studies show that even very low doses of allergen may induce a T-cell response to the allergen (22). Other explanations of the much lower prevalence of allergy among Estonian than Swedish schoolchildren (20), e.g., infections and air pollution (23, 24), must be investigated.

The similar levels of allergen exposure in Estonia and Sweden, two countries with large differences in allergy prevalence, indicate that regional differences are not due mainly to differences in allergen exposure. Thus, the effect of other environmental factors related to lifestyle should be considered. In this respect, differences in the microbial environment may be of particular significance, as this is a major driving force in the maturation in early childhood toward a balanced immune system (24). The higher prevalence of allergy in Western than Eastern Europe may be related more to the loss of environmental factors previously stimulating the immune system than to increasing levels of indoor allergens.

In conclusion, the results of our study indicate that the reported differences in the prevalence of allergy among children and young adults in the formerly socialist countries of Eastern Europe (20, 25) are not due to differences in exposure to indoor allergens. Other environmental factors associated with a modern lifestyle in industrialized countries with a market economy must therefore be explored. Furthermore, the study confirms that sensitization to HDM, cats, and dogs may occur at low exposure levels.

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