

Original Article

Reliability and Correlation Between Indoor Allergen Concentrations from Vacuumed Surface Samples and Electrostatic Dust Collectors

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Submitted 3 July 2019; revised 18 October 2019; editorial decision 27 October 2019; revised version accepted 8 November 2019.

Abstract

Objectives: Most studies on indoor allergen exposure used vacuumed surface samples for quantification. One alternative is electrostatic dust collectors (EDCs), which sample previously airborne settled dust. The aim of this study was to compare allergen quantification using two different sampling methods, with respect to repeatability, and to determine how well the results agree with one another.

Methods: Four times a year, measurements were made from samples that were either collected from the vacuuming of surfaces, or from EDCs, from 20 German day-care centers totaling 167 rooms. Overall, 504 vacuumed samples collected from smooth floors, 435 samples from carpets, 291 samples from upholstered furniture and beds, and 605 EDC samples were analyzed using six fluorescence enzyme immunoassays recognizing Fel d 1, Can f 1, Mus m 1, domestic mite (DM), *Dermatophagoides pteronyssinus* (Dp), and *Tyrophagus putrescentiae* (Tp) antigens. Variances and correlations among the repeat measurements over the course of the year within each sample type, and the correlations between surface samples and the corresponding EDC samples were calculated.

Results: Repeat measurements over the year correlated significantly with one another. However, only Fel d 1, Can f 1, and DM in the EDC samples; DM, Dp, Tp, and Fel d 1 in the upholstered furniture samples; and DM in the carpet samples show representative results of single measurements according to their variance ratios (within-room/between-room variance <1). The highest correlation between surface and EDC samples was found for Fel d 1 on the upholstered furniture (r 0.52), followed

by Can f 1 on the upholstered furniture and Can f 1 on carpets (r 0.47 and 0.45, respectively). The maximum correlation for mite antigens was between carpet samples and EDC (DM r 0.27, Dp r 0.33). Mus m 1 and Tp antigens for the most part did not correlate to the EDC results.

Conclusions: Both vacuumed dust from upholstered furniture and EDC samples were suitable for repeatable quantification of several allergens in day-care centers within a year. However, there was little agreement among the different collection methods, especially for Mus m 1 and certain mite antigens. Therefore, the method and location used for collection may greatly influence allergen exposure assessment and study results.

Keywords: cat allergen Fel d 1; *Dermatophagoides farinae*; dog allergen Can f 1; exposure assessment; house dust mite; mouse allergen Mus m 1; *Tyrophagus putrescentiae*

Introduction

The allergen content in settled or reservoir dust is typically used to provide estimates of indoor exposure levels (Raulf *et al.*, 2014; Grant *et al.*, 2019). Either reservoir dust is collected by vacuuming surfaces, such as mattresses or floors, resulting in allergen levels per m² or per g of dust, or settled previously airborne dust is obtained by passive sampling over a defined period of time, which is usually performed using electrostatic dust collectors (EDCs). The advantage of passive sampling over reservoir dust is that these samples contain deposited particles that were previously in the air; whereas, the vacuumed dust from floors and furniture also comprises material deposited by shoes and clothing. These may be larger and heavier particles that were never airborne (Noss *et al.*, 2008, 2010; Adams *et al.*, 2015). Thus, the settled dust on EDCs that are placed at a height of at least 1.50 m might be more representative of the inhalable dust fraction compared to the reservoir dust from vacuumed surfaces. In a study investigating different sampling methods, settled dust from the EDC was most representative of airborne dust, and may therefore be considered as a surrogate for the assessment of indoor airborne exposure (Frankel *et al.*, 2012). On the other hand, allergen concentrations in EDC samples are more often below the level of detection compared to vacuumed reservoir dust samples (Kristono *et al.*, 2019), and the amount of dust on the EDC tissues is quite often too low to be determined by weighing (Zahradnik *et al.*, 2011).

A number of epidemiological studies have shown conflicting results on the influence of allergen exposure in early life on the subsequent development of sensitization and allergic disease (Chen *et al.*, 2008). Both, the method for exposure assessment and locations of allergen exposure that have not been taken into account, e.g. in day-care facilities, could play a role. In our study on allergen exposure in day-care centers, we used both, vacuuming of reservoir dust and passive sampling of settled dust (Sander *et al.*, 2016b, 2018). For both sample

types, the room type and season of sampling significantly influenced the allergen content which was found to be highest in autumn in almost all cases using multi-level models. However, a systematic comparison and a correlation of allergen results have not yet been performed. Our samples, which were collected in the same rooms by both vacuuming and passive sampling, are the first to offer a comparison of allergen loads, since other studies on allergen exposure in day-care centers or schools used only one collection method, which was mostly vacuuming (Munir *et al.*, 1995; Berge *et al.*, 1998; Perzanowski *et al.*, 1999; Fernández-Caldas *et al.*, 2001; Engelhart *et al.*, 2002; Arbes *et al.*, 2005; Instanes *et al.*, 2005; Zuraimi *et al.*, 2008; Salo *et al.*, 2009; Tranter *et al.*, 2009; Krop *et al.*, 2014).

The surfaces in 167 rooms from 20 day-care centers across the state of North Rhine-Westphalia, Germany were vacuumed four times a year in the different seasons, and EDC were placed in the same rooms starting at the same time for 14 days. In addition to comparing the different collection methods, the correlation of the repeat measurements over the course of the year within a sample type could also be investigated. The main allergens of cat, dog, and mouse (Fel d 1, Can f 1, and Mus m 1), and the mite allergens and antigens of *Dermatophagoides farinae* alias domestic mite (DM), *Dermatophagoides pteronyssinus* (Dp), and *Tyrophagus putrescentiae* (Tp) were quantified in 504 vacuumed samples from smooth floors, 435 samples from carpets, and 291 samples from upholstered furniture and beds, as well as 605 EDC samples.

Material and methods

Sampling in day-care centers

Sampling took place in 20 day-care centers across North Rhine-Westphalia in Germany from 2010 until 2012, as described previously (Sander *et al.*, 2016b, 2018).

Four times a year, surfaces were vacuumed (0.8 m² on smooth floors, 0.4 m² on carpets, and 0.2 m² on upholstered furniture and beds) using ALK dust collection cassettes (ALK-Abello, Hørsholm, Denmark) with glass fiber filters (Macherey & Nagel, Düren, Germany), and EDC with polyester cloths from Zeeman (Alphen aan de Rijn, The Netherlands) were placed on shelves or styro-foam devices for 14 days starting on the same days when vacuuming was performed. Details on sampling and sample extraction were described previously (Sander *et al.*, 2016b, 2018).

Allergen quantification with fluorescence enzyme immunoassays (FEIAs)

The cat, dog, and mouse antibodies and the universal allergen standard were purchased from Indoor Biotechnologies. The mite immunoassays are based on rabbit antibodies to *Dermatophagoides farinae* (DM), Dp, or Tp antigens (Zahradnik *et al.*, 2009, 2011; Sander *et al.*, 2012). The details on FEIA conjugate, substrate, and measurement were previously described (Sander *et al.*, 2016a). The detection limits (LODs) for EDC cloths were 35.9 ng m⁻² for DM, 71.8 ng m⁻² for Dp and Tp, and 7.2 ng m⁻² for Can f 1, Fel d 1, and Mus m 1. The LODs for vacuumed samples from smooth floors were 0.94 ng m⁻² for DM, 1.9 ng m⁻² for Dp and Tp, and 0.19 ng m⁻² for Can f 1, Fel d 1, and Mus m 1. The LODs for vacuumed samples from carpets or furniture were two times or four times higher, respectively, than those for smooth floors.

Statistical analysis

Data management and descriptive data analysis were performed using SAS, version 9.4 (SAS Institute, Inc., Cary, NC, USA) and GraphPad Prism for Windows 8.00 (GraphPad Software, La Jolla, CA, USA). Values below the LOD of immunoassays were replaced by 1/2 LOD. Due to the log-normal distribution of data, the values were log-transformed and Pearson correlation coefficients were estimated. Either the correlations between EDC and surface samples were calculated, or correlations between allergen values obtained with the same sample types from the same rooms in autumn and winter, autumn and spring, autumn and summer, winter and spring, winter and summer, spring and summer, and the average of these correlation coefficients were estimated. In addition, within-room and between-room variances were calculated by mixed-effects models using the restricted maximum likelihood method. The dependent variables in the models were the log-transformed allergen or antigen concentrations. In all models, season

was included as fixed effect and the room of the measurement as random effect. Furthermore, the ratio of within- to between-room variances was estimated. This ratio indicates whether the variation of the repeated measurements within a single room is greater (ratio >1) or less than (ratio <1) the variation of the measurements between different rooms. In case of more than 20% values below LOD the estimates might be severely biased (Hughes, 1999; Lotz *et al.*, 2013) and are marked in the presented tables and figures. Medians and quartiles were calculated using non-transformed values.

Results

Allergen concentrations in samples from day-care centers

The median and quartile results from the vacuumed surface samples and the corresponding (same room and same season) EDC samples are presented in Table 1. With the exception of Can f 1 and Fel d 1 on smooth floors, surface samples were found to more often contain detectable allergen levels compared to the corresponding EDC samples. In particular, *D. pteronyssinus* and *T. putrescentiae* antigens, and to a lesser extent, the mouse allergen Mus m 1, could not be detected in a number of EDC samples, nor in several vacuumed samples from smooth floors. Vacuumed samples from the different surfaces investigated, clearly differed in their allergen content: upholstered furniture contained more allergens per m² than carpets, and both more than smooth floors, which is reflected in the clearly different median and quartile values. In almost all cases, this also applies to surface values if they refer to grams of dust, but with minor differences (the factors between carpet and smooth floor levels are 1–2.5 in terms of allergens per g, and 17–43 in terms of allergens per m²). The difference between carpet and smooth floor was smallest for Mus m 1 and largest for *D. pteronyssinus*.

All allergens that were collected per square meter on EDC cloths during the 14 days gave higher values than those collected on 1 m² smooth floors. Furthermore, these values were also higher than the carpet values for mammalian allergens, but not for mites.

Variances and correlations of the repeat measurements over the course of the year within a sample type

For allergens and antigens, the within-room variance was greater than the between-room variance for the floor samples, with the exception of the DM antigen

Table 1. Median and quartile results of allergen and antigen quantification in 504 vacuumed samples from smooth floors, 435 samples from carpets, and 291 samples from upholstered furniture and beds surface and corresponding EDC samples from 20 German day-care centers.

	EDC		Surface			EDC samples [ng m ⁻² 14 days ⁻¹]			Surface samples [ng m ⁻²]			Surface samples [ng g ⁻¹]		
	<LOD	9.72%	<LOD	9.72%	9.72%	Median	Q1	Q3	Median	Q1	Q3	Median	Q1	Q3
Fel d 1 (smooth floor)	9.72%	9.72%		9.72%	57	17	22	118	1.6	0.6	4.1	128 ^a	51 ^a	285 ^a
Fel d 1 (surface carpet)	7.36%	0.46%		0.46%	67	18	25	131	45.2	16.0	156.7	218	100	427
Fel d 1 (upholstered furniture)	7.22%	0.69%		0.69%	65	18	25	116	189.1	43.0	575.2	687	371	1446
Can f 1 (smooth floor)	5.16%	9.72%		9.72%	53	18	25	114	1.2	0.5	3.5	108 ^a	44 ^a	231 ^a
Can f 1 (carpet)	4.37%	0%		0%	62	18	28	121	31.7	11.5	88.9	146	76	269
Can f 1 (upholstered furniture)	4.47%	0.69%		0.69%	59	17	29	114	104.3	29.4	340.3	402	187	851
Mus m 1 (smooth floor)	17.26%	10.91%		10.91%	17	17	9	27	0.8	0.4	1.5	62 ^a	35 ^a	109 ^a
Mus m 1 (carpet)	13.10%	0%		0%	18	18	11	30	13.5	8.0	25.4	62	40	96
Mus m 1 (upholstered furniture)	15.46%	0.69%		0.69%	18	18	11	29	22.6	11.1	47.6	91	54	133
DM (smooth floor)	3.37%	1.98%		1.98%	369	164	164	819	24.4	9.2	78.5	2207	889 ^a	5147
DM (carpet)	1.61%	0%		0%	444	185	185	1065	890.9	263.7	3618.2	3628	1636	11072
DM (upholstered furniture)	0.34%	0%		0%	496	222	222	1112	2383.4	631.9	12677.5	8868	4099	22364
<i>D. pteronyssinus</i> (smooth floor)	40.08%	36.90%		36.90%	98	98	<72	193	3.2	<1.9	9.0	226 ^a	<LOD	572 ^a
<i>D. pteronyssinus</i> (carpet)	34.48%	1.38%		1.38%	108	108	<72	211	137.9	50.9	414.1	569 ^a	285 ^a	1280
<i>D. pteronyssinus</i> (upholstered furniture)	34.71%	1.89%		1.89%	112	112	<72	224	402.5	113.9	1308.1	1330 ^a	642 ^a	2902
<i>T. putrescentiae</i> (smooth floor)	24.80%	18.45%		18.45%	143	143	<72	272	6.1	2.5	15.0	488 ^a	175 ^a	996 ^a
<i>T. putrescentiae</i> (carpet)	18.39%	0.46%		0.46%	165	165	79	289	169.1	72.7	427.0	706 ^a	425 ^a	1362
<i>T. putrescentiae</i> (upholstered furniture)	21.31%	1.72%		1.72%	159	159	73	289	344.9	116.9	836.8	1056 ^a	719 ^a	2056 ^a

Q1: threshold value between first and second quartile, Q3: threshold value between third and fourth quartile.

The minimum estimate of median and quartiles are presented in case of results per g that are influenced by values below LOD.

concentration on carpets when expressed as per g dust (Table 2). The within-room variance was smaller than the between-room variance in the EDC samples for Fel d 1, Can f 1, and DM, and in samples collected from upholstered furniture for cat and all mite antigen content, expressed per m².

The mean correlations between allergen values that were obtained with the same sample types from the same rooms over the year are shown in Table 3. The values of repeated measurements in EDC samples and samples from upholstered furniture significantly correlated with each other in nearly all cases. The highest correlations were obtained for cat and dog allergens in the EDC samples, and for mite antigens in the upholstered furniture samples. Repeated measurements on

smooth floors showed lower correlations (r 0.07–0.37), which were not significant in many cases. However, in the majority of cases the correlations between repeated measurements were higher when values per g dust rather than per square meter were compared. Exceptions to this trend were all Mus m 1 measurements, Fel d 1 and Tp measurements on upholstered furniture, and Dp and Tp measurements on smooth floors.

Correlation between allergen levels in surface and EDC samples

Correlations between allergen concentrations (ng m⁻², ng g⁻¹) in surface samples with levels in the corresponding EDC samples were calculated, and the matches between the quartile allocations of the allergen content

Table 2. Ratio of within- to between-room variances of mixed-effects models with log-transformed allergen and antigen values measured in EDC or surface samples as dependent variables with season as fixed and room as random effect.

	Cat Fel d 1	Dog Can f 1	Mouse Mus m 1	DM	<i>D. pteronyssinus</i>	<i>T. putrescentiae</i>
EDC results	0.56	0.81	1.31	0.95	2.43 ^a	1.57 ^a
Smooth floor results per m ²	4.14	5.84	1.84	4.21	4.64 ^a	4.24
Smooth floor results per g dust	2.44	2.43	4.03	2.91	11.92 ^a	4.62
Carpet results per m ²	2.49	4.53	2.33	1.76	3.06	2.67
Carpet results per g dust	1.81	2.22	2.60	0.82	1.25	1.61
Upholstered furniture results per m ²	0.94	1.16	1.30	0.69	0.84	0.97
Upholstered furniture results per g dust	1.04	1.07	3.38	0.54	0.59	1.05

If within-room variance is smaller than between-room variance, values are printed in bold.

^aEstimates are biased due to more than 20% values below LOD.

Table 3. Means of Pearson correlation coefficients of log-transformed allergen and antigen values in EDC or surface samples taken over different seasons in the year.

	Cat Fel d 1	Dog Can f 1	Mouse Mus m 1	DM	<i>D. pteronyssinus</i>	<i>T. putrescentiae</i>
EDC results	0.65*	0.56*	0.43*	0.53*	0.28 ^{a,g}	0.39* ^g
Smooth floor results per m ²	0.20 ^{e,f}	0.16 ^{a,d,e,f}	0.37*	0.21 ^{c,f}	0.18 ^{a,e,f,g}	0.21 ^f
Smooth floor results per g dust	0.28 ^c	0.29 ^a	0.16 ^{a,c,d,e}	0.27 ^d	0.07 ^{a,b,c,d,e,g}	0.19 ^{a,b,d,f}
Carpet results per m ²	0.32 ^{b,d,f}	0.19 ^{b,d,f}	0.33 ^{d,f}	0.39 ^f	0.27 ^f	0.31 ^{b,f}
Carpet results per g dust	0.36*	0.29*	0.29 ^a	0.56*	0.44*	0.39*
Upholstered furniture results per m ²	0.56*	0.48*	0.46*	0.60*	0.55*	0.54*
Upholstered furniture results per g dust	0.53*	0.50*	0.25 ^{b,d,e,f}	0.66*	0.61*	0.50*

^aSpring values not significantly correlated with summer values.

^bSpring values not significantly correlated with autumn values.

^cSpring values not significantly correlated with winter.

^dSummer values not significantly correlated with autumn values.

^eSummer values not significantly correlated with winter values.

^fAutumn values not significantly correlated with winter values.

^gEstimates are biased due to more than 20% values below LOD.

*All correlations significant, mean correlation coefficients in bold, values are italicized if ratio of within-room variance to between-room variance is <1 (see Table 2).

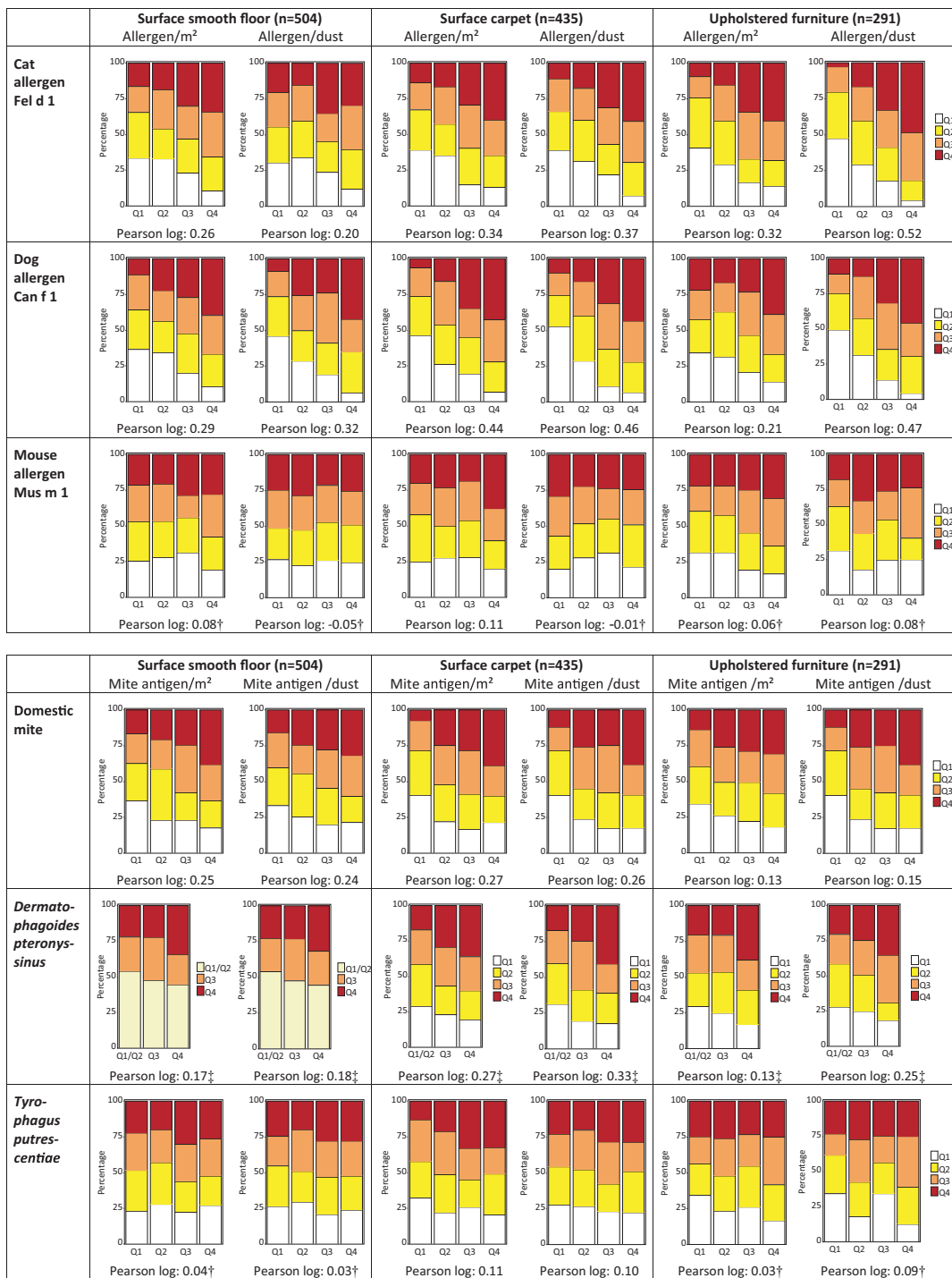


Figure 1. Comparison between results of EDC and vacuumed surface samples for the different allergens and surface types. The graphs show the quartile assignment of EDC results (quartiles in columns) in comparison to the quartile assignment of the surface results (quartiles in different colors) from same rooms and the same season. Q1: values $\leq 25\%$; Q2: values $>25\% \leq 50\%$; Q1/Q2: values $\leq 50\%$; Q3: values $>50\% \leq 75\%$; Q4: values $>75\%$. Pearson correlation coefficients (of log values) were calculated and marked with a dagger (†) in case of P -values >0.05 , and with a double dagger (‡) in case of uncertain results due to the high number of values $< \text{LOD}$.

of the samples collected from the different locations were graphically illustrated (Fig. 1). Significant correlations were obtained in most cases, with exceptions, for example in the case of mouse allergen Mus m 1 or Tp antigens. The correlation of EDC samples with upholstered furniture samples (allergen/g dust) was highest for cat and dog allergens (r 0.52 and 0.47, respectively). The graphs show the proportion of samples with the same quartile allocations. For example, about half of the matched cases with EDC Fel d 1 values above the 75% quantile had Fel d 1 values (ng g^{-1}) on furniture surfaces that were also above the 75% quantile. On the other hand, only 29% of the cases with EDC Fel d 1 values below the 25% quantile also had Fel d 1 values (ng g^{-1}) below the 25% quantile on smooth floors. In this case, the correlation between Fel d 1 in EDC and smooth floor samples was also low (r 0.20).

The correlations for house dust mite antigens in EDC and surface samples were generally lower than those for cat and dog allergens. For house dust mite antigens the correlations were highest between EDC and carpet samples (r 0.26–0.33).

Discussion

In the day-care centers, the main cat and dog allergens, Fel d 1 and Can f 1 were detectable in more than 90% of the EDC, as well as vacuumed samples from smooth floors, and in more than 99% of the carpet and upholstered furniture samples when sensitive FEIA methods were used. Nearly all samples were above the LOD for DM allergens and antigens measured using a polyclonal antibody-based FEIA. This differs from the detection of single house dust mite allergens with monoclonal antibody-based assays, which are difficult to measure in EDC and airborne dust samples. In studies from the Netherlands and Germany (Sander *et al.*, 2012; Krop *et al.*, 2014), only few samples contained measurable levels of Der f 1 or Der p 1. Furthermore, despite the high mite load reported in New Zealand (Wickens *et al.*, 1997), Der p 1 could only be detected in 15% of the EDC samples collected in bedrooms (Kristono *et al.*, 2019), although a sampling period of 4 weeks and a sensitive ELISA variant was used (Tovey *et al.*, 2016). Therefore, quantification of house dust mite allergens by polyclonal antibody-based assays, which simultaneously detect numerous allergens and antigens might be the method of choice when analyzing EDC samples. Using the DM FEIA revealed that a large majority of EDC samples were above the LOD in schools and homes in the Netherlands (Krop *et al.*, 2014), as well as in German homes (Sander *et al.*, 2018). This assay is

based on polyclonal antibodies to the house dust mite *Dermatophagoides farinae* which is the most frequently detected mite in Germany, according to previous studies (Kuehr *et al.*, 1994; Zock *et al.*, 2006). The FEIA which is based on polyclonal antibodies to *D. pteronyssinus*, was positive in only 60% of the EDC samples and 63% of the vacuumed samples from smooth floors in the day-care centers, which was even lower than the detection rate of Tp antigens. The same ranking of mite detection rates was obtained in the EDC samples that were collected in parallel to the day-care centers in the children's and day-care workers' homes (Sander *et al.*, 2018). Most samples were positive for DM (84%) (Sander *et al.*, 2018), followed by 47% positive for Tp, and 42% above the LOD for Dp (unpublished data). Although the different detection rates between DM and the other mites may be also due to the higher sensitivity (twice lower LOD) of the DM FEIA compared to both the Tp and Dp FEIA, the data confirm that *D. pteronyssinus* is not the dominant DM species in Germany.

Knowledge about the repeatability of allergen measurements over time is important when efficiently designing studies to investigate the role of these biocontaminants in the induction and maintenance of allergic diseases (Topp *et al.*, 2003). Previous studies on the repeatability of indoor allergen measurements over time have been mainly performed in private homes, and in most cases in vacuumed surface dust (Kuehr *et al.*, 1994; Marks *et al.*, 1995; Hirsch *et al.*, 1998; Peterson *et al.*, 1999; Heinrich *et al.*, 2003; Topp *et al.*, 2003; Antens *et al.*, 2006). Correlation coefficients among the repeated measurements were reported to be between 0.21 and 0.82 depending on the vacuumed surface, the time interval between the measurements, and the allergen examined (Kuehr *et al.*, 1994; Heinrich *et al.*, 2003; Topp *et al.*, 2003). In most cases, between-house variability was higher than within-house variability (Hirsch *et al.*, 1998; Heinrich *et al.*, 2003; Antens *et al.*, 2006), which is considered sufficiently stable for allergen exposure estimation (Heinrich *et al.*, 2003; Antens *et al.*, 2006).

To estimate allergen exposure in German day-care centers, repeated measurements over the year were performed, both in vacuumed surface samples and in EDC samples. Variability of measurements clearly depended on the sample type. The correlation coefficients of repeated measurements on smooth floors were low (r 0.07–0.37), and the within-room variability was in all cases higher than the between-room variability (variance ratios >1). Higher correlations were obtained for repeated measurements on carpets (r 0.19–0.56), upholstered furniture (r 0.25–0.66), and in EDC samples (r 0.28–0.65).

The underlying reasons for the variability among allergen measurements on smooth floor have not been fully investigated. Similar to the results we obtained in day-care centers, the mite allergen variance ratios for floors with smooth surfaces were significantly higher compared to the variance rates for carpets in the Prevention and Incidence of Asthma and Mite Allergy Birth Cohort Study (Antens *et al.*, 2006), and the repeatability of allergen estimations from beds was better than the repeatability of estimations from carpeted floors (Marks *et al.*, 1995). However, correlation coefficients (r 0.65–0.75) of repeated measurements of mite and cat allergens on living room floors, arising mainly from carpets, were considerably higher in the Indoor Factors and Genetics in Asthma study (Heinrich *et al.*, 2003) compared to those observed in our study on day-care center floors. It is possible that the more frequent cleaning at the day-care centers compared to private homes may contribute to the lower correlations of allergen levels in floor dust over the year. Low correlation, as well as higher within-room variance compared to between-room variance means that single measurements of floor samples, at least of smooth floors, cannot reliably determine the allergen load in day-care center rooms. An exception to this rule is the DM concentration (per g dust) on carpets, which seems to be more representative of a room over the year (variance ratio 0.82). Furthermore, variance ratios below 1 were observed for mite antigens and Fel d 1 on upholstered furniture and for Fel d 1, Can f 1, and DM in EDC samples. Thus, even single measurements of these allergens in such samples seem to be representative of day-care center rooms within a year.

Correlations between allergens in surface and EDC samples from the same rooms in the day-care centers were also examined. To date, there are no other known studies comparing surface and EDC samples collected at the same time at day-care centers with regard to allergen concentrations, but studies do exist comparing different sampling methods at homes. Whereas Peterson *et al.* (1999) found no or only little correlation between surface and airborne Fel d 1, Der f 1, and Der p 1 levels in the Detroit area, Fel d 1 on EDC cloths collected from homes in New Zealand correlated with the reservoir levels from bedroom floors and mattresses (r 0.672 and 0.613, respectively) (Kristono *et al.*, 2019). No correlation was found between Der p 1 levels in surface dust and in EDC samples. In both studies, single house dust mite allergens (e.g. Der p 1) were detected in only a minority of the airborne dust or EDC samples (23.9% or 15%, respectively). Therefore, the lack of correlation between airborne or EDC samples with surface samples for the house dust mite allergens should

be interpreted with caution. However, in our study using the Dp and DM FEIAs with 61% and 96% of the EDC samples above LOD, respectively, small but significant correlations were observed with surface dust samples (best value obtained to carpet samples, r 0.33 and 0.27, respectively).

Moderate correlations were observed for cat and dog allergens in EDC and upholstered furniture or carpet samples (best value obtained for Fel d 1 in upholstered furniture samples, r 0.52). The correlations for Fel d 1 are lower than those previously reported (Kristono *et al.*, 2019). Therefore, the conclusion that both collection methods appear to similarly assess Fel d 1 exposure does not apply to exposure in German day-care centers.

Finally, no significant correlation was observed between EDC and surface samples for Mus m 1 and Tp antigens in nearly all cases. Correlations between surface samples and EDC samples for Tp and mouse allergens have not been previously investigated; however, in a laboratory animal facility, mouse allergens in EDC samples closely correlated to their airborne levels measured over 12 h with stationary samplers connected to pumps (Feistenauer *et al.*, 2014). Thus, exposure assessment by EDC might be an appropriate method, especially in cases where exposure is higher than those in day-care centers.

Conclusions

The most relevant allergens in day-care centers—Fel d 1, Can f 1 and DM—were detectable in the vast majority of samples. However, since repeatability was low among samples collected from smooth surfaces, exposure assessment based on single measurements of this sample type is not recommended. In contrast, Fel d 1, Can f 1, DM in EDC samples; mite antigens and Fel d 1 in upholstered furniture samples; and DM in carpet samples showed representative results of single measurements. However, the correlation between measured allergen amounts in EDC and surface samples was low or moderate at best, indicating that the choice of sampling method, especially for mite allergens might have a great influence on exposure assessment and study results.

Acknowledgments

The study was conducted with the support of the Unfallkasse Nordrhein-Westfalen der Deutschen Gesetzlichen Unfallversicherung, Düsseldorf, Germany. We acknowledge especially the efforts of Martin Buxtrup, Michael Stolle, and Wolfgang Swoboda for visiting the day-care centers and collecting samples. In addition, we would like to thank Rosemarie Marchan for improving the language.

Conflict of interest

The authors declare that there exists no conflict of interest.

Funding

The study was financed by the Deutsche Gesetzliche Unfallversicherung (project IPA-47).

Declaration

The authors designed and executed the study and have sole responsibility for the writing and content of the manuscript.

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