



Effectiveness of a portable air filtration device in reducing allergen exposure during household chores

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Abstract

Background Exposure to airborne allergens is an important risk factor for sensitization, allergic rhinitis and asthma. The aim of this study is to verify whether the use of an air filtration device, called “air purifier” (AP) is able to reduce indoor allergen exposure.

Methods In three rooms of one household with pets (a cat and a dog), inhalable dust was sampled with transportable pumps for 1–2 h during typical household chores on 15 days—either in the morning without the AP or in the afternoon using an AP. In addition to sampling inhalable dust both with a stationary and a personally carried pump with Teflon filters, nasal filters were used. Inhalable dust on the Teflon filters was quantified gravimetrically, and allergen content was measured on all filters ($n=90$) using fluorescence enzyme immunoassays for domestic mites (DM), the cat allergen Fel d 1, and the dog allergen Can f 1.

Results The use of the AP significantly reduced inhalable dust in both personal and stationary samples by 40 or 20%, respectively. In most cases, allergen exposure was also reduced; the median allergen concentrations in the air were up to 60% lower with the AP than without. Allergen exposure varied greatly, and with the exception of Can f 1 sampled with the personally carried pump, and DM allergens in the nasal samples, there was no significant difference with or without an AP.

Discussion Typical household chores can result in high levels of exposure to indoor dust and allergens. The use of an AP however can reduce the inhalable dust concentrations, but the effect on allergen exposure was in most cases not large enough to achieve statistical significance.

Keywords Indoor allergen exposure · Domestic mite · Pet allergens · Dust collection · Air filtration

Abbreviations

AP	Air purifier
DM	Domestic mites
ELISA	Enzyme-linked immunosorbent assay
FEIA	Fluorescence enzyme immunoassays
HEPA	High-efficiency particulate air
LOD	Lower limit of detection
PBS	Phosphate-buffered saline

Introduction

Exposure to airborne allergens of biological origin is an important risk factor towards the development of allergic rhinitis and asthma. The success of primary prevention strategies, including allergen avoidance or exposure reduction in early childhood are still controversial; however, secondary prevention measures are still recommended in order to avoid aeroallergen exposure in patients with allergic respiratory symptoms [1]. Cessation or reduction of exposure is also a key element for the prevention and management of occupational asthma and allergy [2]. Due to prevention measures, complete allergen avoidance is possible at some, but not all workplaces, as contact to allergen sources is often unavoidable. For example, allergen exposure during the handling of dogs, cats, and other animals with fur or hair at veterinary practices cannot be avoided. In addition, domestic mites are om-

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nipresent, and during housework, particles containing allergens may become airborne and can then be inhaled.

In households and workplaces with sensitized individuals, the application of air filtration with high-efficiency particulate air (HEPA) filters may be useful to reduce the allergen load and allergy symptoms [3]. However, previous studies with portable room air cleaners focusing mostly on pet allergy have shown inconsistent and limited success [4–7]. For example, in a double-blind placebo-controlled trial with adult patients suffering from cat induced asthma and rhinitis, the clinical effects of air filtration in the bedroom alone over a 3 month period were too low to be differentiated from the placebo group [4]. In combination with mattress covers, the use of air-cleaners over 6 months contributed towards the improvement of airway hyperresponsiveness in adult house dust mite allergic asthmatic patients [5]. In one study with children, air filtration in the bed- and living room led to a moderate effect on pet allergy symptoms after 3 months; more specifically, there was a significant improvement in airway hyperresponsiveness and a decrease in peak flow amplitude. In contrast, no effect was seen on symptom score or lung function, expressed as FEV₁ (forced expiratory volume in 1 s) [6]. In a randomized controlled trial, HEPA air filtration in the bed- and living room over a 6- and 12-month period retained a significant amount of airborne pet allergens on the filters. However, there was only a small improvement in bronchial hyperresponsiveness in the 17 asthmatic children suffering from cat and dog allergy, which was not significantly different from the control group with sham filters [7]. Since pet allergen concentrations in bulk dust did not change during this trial, and no air samples were taken, the efficiency at which air filtration reduces airborne allergens remains uncertain. However, in other studies [8, 9] airborne samples collected by pumps before and after air filtration over 4 to 8 h in rooms without activity indicated a reduction in cat and dog allergens by 80 and 90%, respectively.

One reason for the lack of or minor effects of air filtration on clinical symptoms may be due to lax adherence turning on air filtration every day for 24 h due to the noisiness of the devices. Francis et al. [10] observed a small but significant improvement in the combined asthma outcome (bronchial reactivity and treatment requirement) in a randomized, parallel-group study of 30 asthmatic cat or dog sensitized patients, especially in those who ran the air cleaners for longer periods of time.

Modern air filtration devices are able to automatically adapt their airstream (and noise) according to the amount of airborne dust particles, and therefore could result in better compliance with continuous usage. So far, no allergen avoidance studies have been performed with these improved air filtration devices.

In addition, there are no data currently available on the efficiency of air filtration for the reduction of airborne mite allergens, which are difficult to detect in airborne samples since the larger particles (>10 µm) that carry the majority of mite allergens of group I and II tend to settle soon after becoming airborne [11]. In order to measure airborne mite allergen concentrations, pumps with high throughput, sensitive detection methods, and/or activity during measurements are necessary [12, 13]. The domestic mite (DM) immunoassay based on polyclonal antibodies to *Dermatophagoides farinae* allergens enables personal exposure assessment since it detects many antigens from several domestic mite species, as well as the majority of house dust mite allergens [14, 15].

The aim of this study is to verify whether the use of a modern device for HEPA air filtration (AP) is capable of reducing indoor allergens, in particular the exposure to house mites during housework. Similar activities were performed either with or without the AP, and mite allergen as well as dust and pet allergen concentrations in personal and stationary samples were compared. In addition to standard air sampling with pumps, nasal samplers were used in parallel as a more direct approach to assess allergen exposure, since they directly collect particles that enter the human body via the nasal cavity.

Methods

Study design and sampling

Inhalable dust was sampled with both a stationary and a personally carried pump (GSA SG 10-2) in three different rooms (bedroom, living room and study room) of one household with a castrated tomcat (part of the household for 2 years) and a castrated female Bernise Mountain Dog (5 years in the household) at a flow rate of 10 l/min on preweighed Teflon filters with GSP-sampling heads. The samples were either taken in the morning without active AP or in the afternoon using a Philips AP (Philips AC3256) that was equipped with a Philips FY3433 HEPA and a Philips FY3432 activated carbon filter. The AP was started one hour prior to the start of sampling in the room, and constantly run at its maximum (with a clean air delivery rate of 367 m³/h). The sampling head of the personally carried pump was placed near to the mouth of the investigator who also performed the housework. The stationary pump was positioned on a rack in the middle of the room, with the sampling head also positioned at face height. The room plans, including the position of the AP and the stationary pump are shown in Fig. 1. No pet was present in the rooms on days of measurement, but on other days, both animals were allowed in all rooms.

Nasal filters (Rhinix, Aarhus, Denmark; size L) were also worn by the investigator to collect inhaled airborne dust during typical household chores. The nasal filters were inserted directly into the nostrils to re-



Fig. 1 Location of sampling and placement of the air purifier and the rack with the stationary pump. Bedroom 50 m³ (a), study room 69 m³ (b), living room 101 m³ (c)

move dust particles from the inhaled air [16], and the nasal samples were collected during the pump measurements.

Duration of measurements varied between one and two hours, and the stationary and the personally carried pump were started simultaneously. The pump flow was regularly checked. During sampling in the morning and afternoon, identical household activities were carried out. In each room, measurements were repeated five times over a period of 7 weeks (24 August 2017 to 11 October 2017) with varied activities on different days (Table 1). The vacuum cleaner used had no HEPA filter.

Overall, 90 samples were taken; 30 with the pump that was carried by the investigator, 30 with the stationary pump in the middle of each room, and 30 nasal samples. Thus, 15 stationary samples without the AP and 15 stationary samples with the AP; 15 personal samples without the AP and 15 samples with the AP and 15 nasal samples without the AP and 15 nasal samples with the AP could be compared.

Weighing and filter extraction

All samples were frozen (−20 °C) for 24 h. After conditioning for 24 h in the climate-controlled room, the dust load on the filters from personal and stationary samples was weighed. One filter contained very little dust and as a result no weight could be recorded. For graphics and evaluation, the value was set to half the minimum of the other measured weights. Teflon and nasal filters were extracted for allergen quantification in phosphate-buffered saline (PBS) with 0.05% Tween 20 (5 ml or 1.2 ml, respectively), and rotated for 1 h at room temperature. All extracts were centrifuged for 15 min at 3000 × g, and supernatants were stored in aliquots at −80 °C until testing [14].

Allergen quantification

The allergen content was quantified with sensitive fluorescence enzyme immunoassays for the main cat allergen Fel d 1, the main dog allergen Can f 1, and with a polyclonal antibody-based assay for domestic mite allergens [14, 17]. The domestic mite allergen concentrations are higher compared to assays used to detect single allergens. According to a previous comparison [14], a significant correlation was obtained for DM and Der f 1 values, but the DM values were approximately 144-fold higher than Der f 1 levels using the monoclonal antibody-based immunoassay and the multiallergen standard from Indoor Biotechnologies Ltd. (Charlottesville, VA, USA) [14]. To detect the main allergens from the cat and dog, monoclonal antibodies and multiallergen standards were purchased from Indoor Biotechnologies. The kit, EL-FD1, was employed to measure Fel d 1. For detection of Can f 1, the monoclonal antibody 6E9 was biotinylated with a 33 molar excess of biotin-ε-aminocaprylic-N-hydroxysuccinimide ester (Roche, Mannheim, Germany), and the monoclonal antibody 10D4 was utilized as the capture antibody [17].

All assays were performed as amplified fluorescence enzyme immunoassays (FEIA) using streptavidin peroxidase conjugate poly-HRP80-SA (Fitzgerald, Concord, MA, USA) and the fluorogenic substrate, Quanta blue (ThermoScientific, Rockford, IL, USA). Sample concentrations were calculated by interpolation of relative fluorescence units on a four-parameter fitted standard curve using Softmax Pro 5.4.1 (Molecular Devices, Sunnyvale, CA, USA). The lower limit of detection (LOD) for the amplified FEIAs

Table 1 Activities during sampling and sampling duration

Room	Sweeping [min]	Tidying up [min]	Plumping up of pillows, blankets, carpets [min]	Wiping dust [min]	Vacuuming [min]	Sampling time [min]
Study room	10	25	5	20	10	120
	10	15	5	20	10	120
	0	15	5	15	10	60
	10	10	5	20	5	60
	0	20	5	20	15	120
Bedroom	5	15	10	20	10	120
	5	10	20	20	10	120
	0	5	15	10	15	60
	5	10	10	10	5	60
	0	10	20	15	15	120
Living room	10	20	5	20	10	120
	10	25	5	10	10	120
	0	20	5	10	10	60
	5	15	20	0	10	60
	0	20	5	15	20	120

were 0.05 ng/ml for DM, and 0.01 ng/ml for Fel d 1 and Can f 1 [17].

Statistical analysis

Since the data were log-normally distributed (Kolmogorov–Smirnov test), the results were compared with the paired t-test of log-transformed values. A *p*-value below 0.05 was considered statistically significant. Pearson correlations of log-transformed values were calculated. All data were analyzed and visualized by using GraphPad Prism 7.04 for Windows (GraphPad Software, La Jolla, CA, USA). The Bland–Altman Plots show the %Difference ($100 \times (\text{value with AP} - \text{value without AP}) / \text{average} ((\text{value with AP} + \text{value without AP}) / 2)$). In case of values below the detection limit, the value was set to $\frac{1}{2}$ of this limit for analysis and graphs.

Results

Dust in stationary and personally carried samples

Nearly all filters contained enough dust for gravimetric analysis (Fig. 2). The maximal dust amount was found in the bedroom (4.72 mg/m³). The only sample without weighable dust was obtained by stationary sampling in the study room in the presence of the AP (lowest point in Fig. 2a). In most cases, the dust sampled in the presence of the AP was lower than without the AP (Fig. 2b), and the median values were also lower (Fig. 2a). In both, the personal and stationary samples, airborne dust was significantly reduced by the AP (paired t-test of log-transformed values: *p*=0.0167 and *p*=0.0335, respectively). Overall, the airborne dust was highest in the bedroom, followed by the study, and lowest in the living room. Sweeping, dusting and shaking pillows, blankets or carpets generated the highest dust levels, and airborne dust be-

came elevated with increased percentage of these activities during the sampling period (data not shown).

Allergens in stationary and personally carried samples

Domestic mite allergens were detected in all samples that were measured (Fig. 3). The highest levels were measured in the bedroom with a maximum of 319 ng/m³ and the lowest was found in the living room with 1.4 ng/m³. Using the AP resulted in no statistically significant difference in the allergen levels (paired t-test of log-transformed values), although median DM allergen concentrations were lower in samples collected with the AP than without (medians: personal without AP 24 ng/m³, with AP 15 ng/m³; stationary without AP 7.3 ng/m³, with AP 6.3 ng/m³). The Bland–Altman plot shows many cases where the allergen levels were not decreased with the AP (Fig. 3b).

In addition, the cat allergen Fel d 1 was detectable in all samples (Fig. 4). The levels of Fel d 1 varied between 65 ng/m³ (in bedroom) and 0.2 ng/m³ (in living room). In personal samples, the median Fel d 1 level was 63% lower through the use of air filtration; whereas, stationary measurements showed few differences (medians: personal without AP 3.58 ng/m³, with AP 1.31 ng/m³; stationary without AP 1.17 ng/m³, with AP 1.03 ng/m³). Nevertheless, the differences were not significant (paired t-test of log-transformed values). The Bland–Altman plot shows many cases without allergen reduction when the AP was used (Fig. 4b).

The dog allergen Can f 1 was measurable in all samples (Fig. 5). The highest level was measured in the bedroom (57 ng/m³), the lowest level in the living room (1.79 ng/m³). In the personal samples, the Can f 1 level was significantly decreased using the AP (paired t-test of log-transformed values: *p*=0.0192). In this case, the median was approximately 40% lower than without air filtration (medians: personal

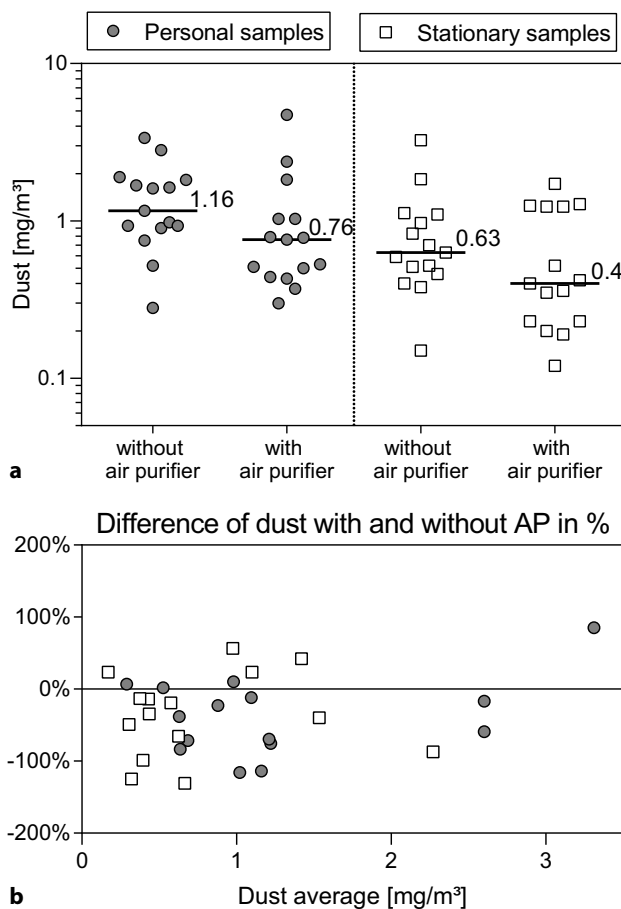


Fig. 2 **a** Airborne dust measured on personal and stationary samples with or without use of air purifier (AP) including medians. **b** Bland–Altman plot of the same data, with the differences in percentage of the average versus the average (values < 0 are obtained if values with AP are smaller than values without AP)

without AP 9.58 ng/m³, with AP 5.67 ng/m³). The Bland–Altman plot shows 11 out of 15 cases with allergen reduction when the AP was used (Fig. 4b). In the stationary samples, the level of Can f 1 did not differ significantly (paired t-test of log-transformed values: $p=0.065$), although the median was 40% lower through air filtration (medians: stationary without AP 5.50 ng/m³, with AP 3.41 ng/m³), and 10 out of 15 cases had lower dog allergen levels with the AP.

For all allergens, the levels were highest in the bedroom, followed by the study and lowest in the living room. In addition, allergen levels became elevated with an increased percentage of “dusty” activities during the sampling period (data not shown).

Allergens in nasal samples

In all measured nasal samples DM allergens, Can f 1 and with one exception, Fel d 1 were detected (Fig. 6). The highest levels of DM allergens were measured in the bedroom with a maximum of 61 ng/filter, and the lowest level was found in the living room with

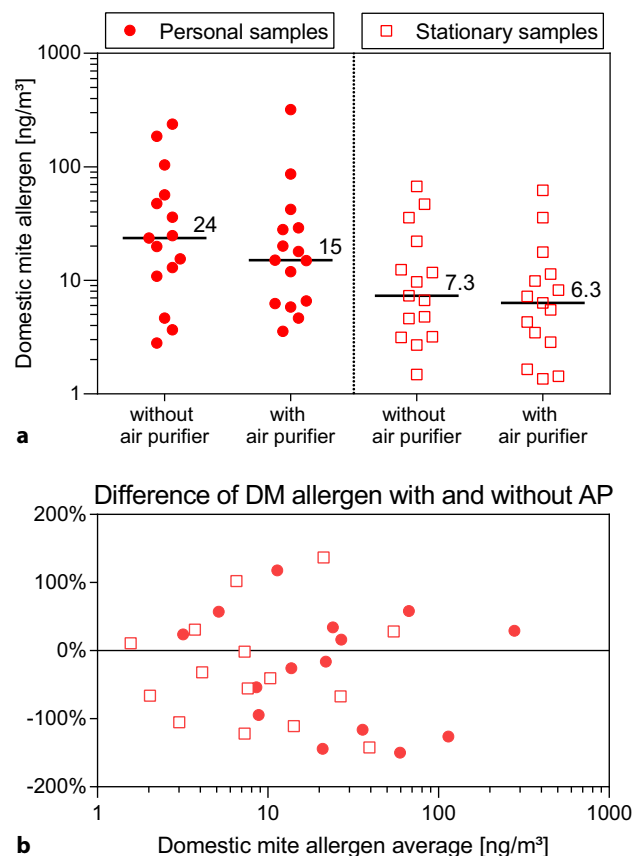


Fig. 3 **a** Domestic mite allergens measured in personal and stationary samples with or without use of air purifier (AP) including medians. **b** Bland–Altman plot of the same data, with the differences in percentage of the average versus the average (values < 0 are obtained if values with AP are smaller than values without AP)

0.7 ng/filter. Using the AP caused a statistically significant difference in the DM allergen level (paired t-test of log-transformed values: $p=0.036$). In the Bland–Altman plot, 11 out of 15 cases had lower values with the AP (Fig. 6b). The median with the AP was 60% lower than without (medians: without AP 8.7 ng/filter, with AP 3.3 ng/filter).

The highest Fel d 1 level was measured in the bedroom (20 ng/filter), the lowest level in the living room (<0.012 ng/filter). Although using the AP reduced median Fel d 1 values by 60% (medians: without AP, 0.47 ng/filter; with AP 0.18 ng/filter), the difference was not significant (paired t-test of log-transformed values: $p=0.286$).

The Can f 1 levels varied between 13 ng/filter in the bedroom and 0.4 ng/filter in the living room. In nasal samples, the level of Can f 1 did not differ significantly (paired t-test of log-transformed values: $p=0.568$, medians: without AP 2.89 ng/filter, with AP 2.35 ng/filter).

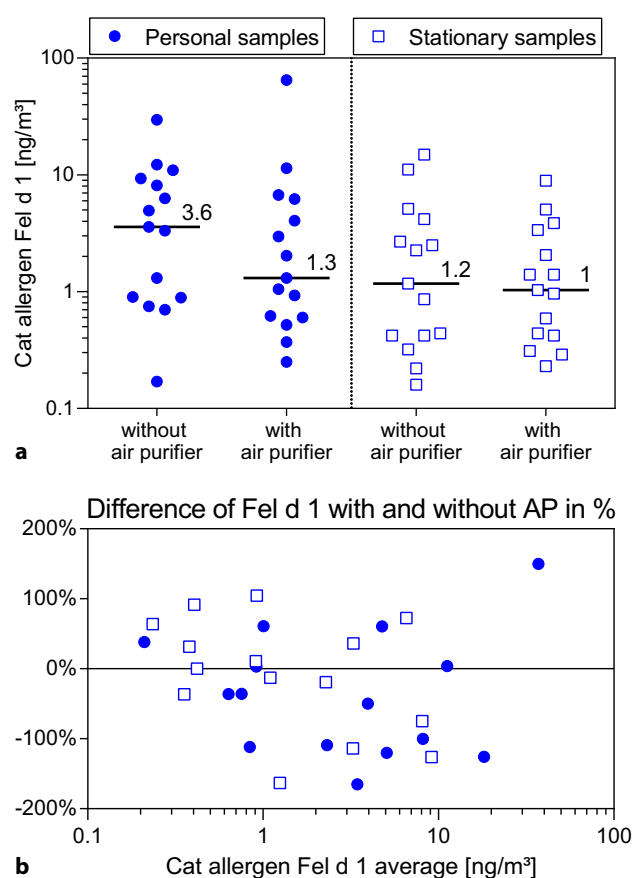


Fig. 4 **a** Cat allergen Fel d 1 measured in personal and stationary samples with or without use of air purifier (AP). **b** Bland–Altman plot of the same data, with the differences in percentage of the average versus the average (values < 0 are obtained if values with AP are smaller than values without AP)

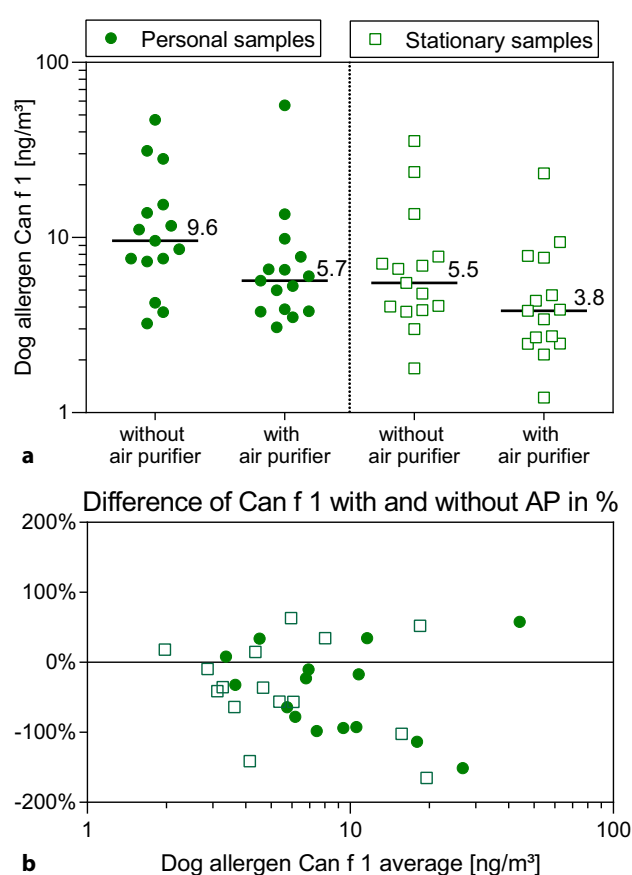


Fig. 5 **a** Dog allergen Can f 1 measured in personal and stationary samples with or without use of air purifier (AP). **b** Bland–Altman plot of the same data, with the differences in percentage of the average versus the average (values < 0 are obtained if values with AP are smaller than values without AP)

Correlations

Significant correlations were observed between all measured parameters when all samples were included (Table 2). The correlations were determined for stationary, personal and nasal samples. The highest correlation was observed between dust load and Fel d 1 in personal samples; the lowest correlation was between dust load and DM allergens. Furthermore, a high correlation between the different sampling strategies to assess allergen concentrations was found (Table 3). The correlations between personal and stationary samples were higher than correlations between pump and nasal samples.

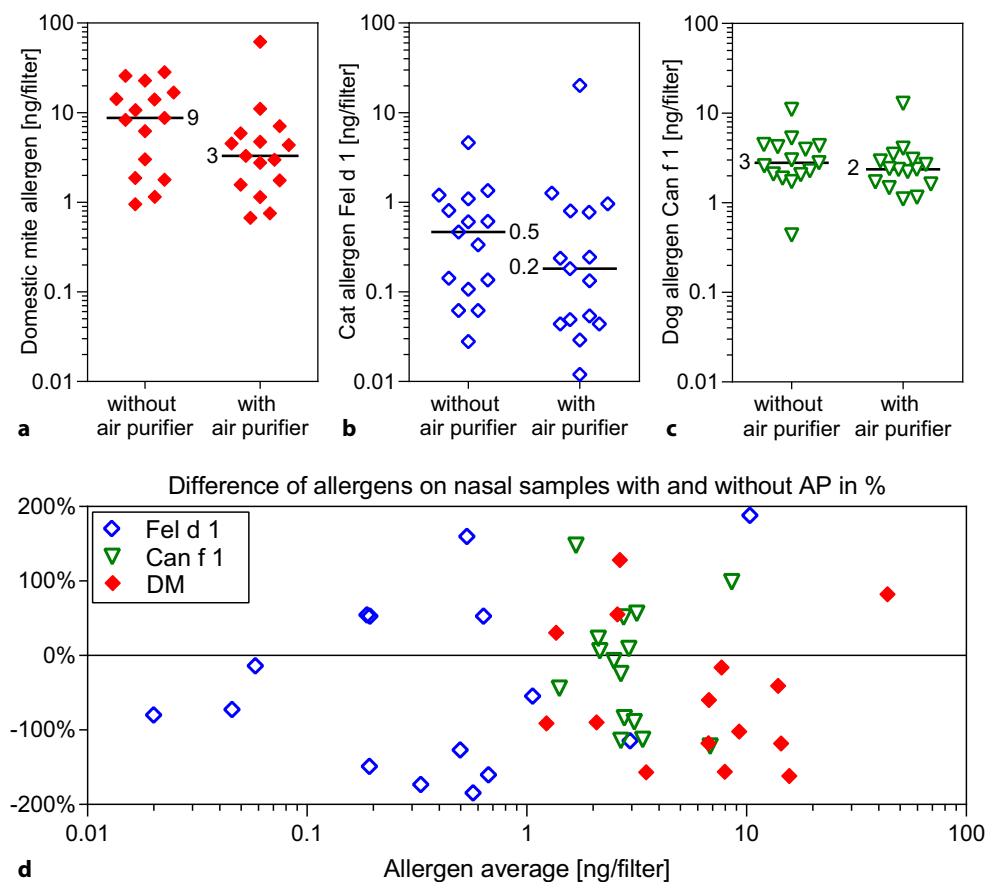
Discussion

Personal, as well as nasal samples indicate that there is considerable pet and mite allergen exposure during household chores. The allergen exposure varied depending on the activity during measurement and the room. The dust and different allergen levels were correlated, showing a dominating influence of activity on exposure levels.

With a clean air delivery rate of $367\text{m}^3/\text{h}$, the AP that was used in the study should be able to filter the air volume of the living-, study and bedroom 3–7 times per hour. However, even air filtration at this rate could not prevent allergen exposure during intensive house-keeping activities. Domestic mite allergens, as well as cat and dog allergens could be detected in all personal and stationary samples, and with the exception of one sample, in all nasal samples obtained in the presence of the active AP.

In order to compare the exposure during housework with and without air filtration, similar activities were performed. One half of the room was processed in the morning, and the other half in the afternoon, with the investigator taking special care to perform exactly the same activities during both periods. However, stirring up dust and allergens during housework is a random and dynamic process that is expected to result in a high variation of local airborne concentrations. Therefore, the differences observed between measured concentrations without and with the AP are only partly due to air filtration. Thus, in several cases, the measurements in the afternoon with air filtration were even higher than those obtained in the morning

Fig. 6 Domestic mite allergens (a), Fel d 1 (b) and Can f 1 (c) measured in nasal samples with or without use of air purifier (AP). **d** Bland–Altman plot of the same data, with the differences in percentage of the average versus the average (values < 0 are obtained if values with AP are smaller than values without AP)



without. However, for most cases the Bland–Altman analysis revealed a reduction in dust levels, as well as a reduction in allergen concentrations with active air filtration. The median values were lower with the AP for all cases. However, in the paired t-test the results did not differ significantly with or without the AP, with the exception of inhalable dust, dog allergen sampled by personal carried pumps, and DM allergens on the nasal samplers.

Our results suggest that mite and pet allergens were very similar in terms of the differences observed between samples with or without the AP. It had been assumed that air filtration is not as effective for mite allergens as for pet allergens [4, 6], as the latter are partly bound to smaller particles, which remain airborne for prolonged periods of time, while most mite allergens are attached to larger particles that settle more rapidly [11]. However, the majority of the major cat or dog allergens are also predominantly associated with large particles [8, 18]. One hypothesis is that the continuous activity during measurements in our study has helped to keep the larger particles in the air and contributed to a similar behavior among the different allergens, thereby increasing the correlation between mite and animal allergen levels.

Previous studies on the effectiveness of air filtration with measurements of airborne cat and dog allergens reported a significant reduction in cat and dog allergens by 80 and 90%, respectively [8, 9]. In contrast to

our investigation, the measurements were performed with stationary pumps in the absence of any disturbance after air filtration over periods of four or seven hours. Even in controls without air filtration, a reduction of airborne allergens was observed without activity, most probably due to the settlement of larger particles.

Gore et al. [19] in a study design similar to ours, were the first to use nasal air samplers to quantify Fel d 1 in the presence or absence of air filtration. During the measurements, the investigators remained sedentary, and the majority of the ELISA (enzyme-linked immunosorbent assay) measurements were below the LOD (0.4 ng/ml Fel d 1, corresponding to 0.12 ng/ml Fel d 1 in the multiallergen standard [20]). However, Fel d 1 could be quantified with a more sensitive immunostaining method (“HALOgen assay”) and was shown to significantly decrease with air filtration at a flow rate of 221 m³/h, especially when a cat was in the room or after 3 h of air filtration [19]. The maximum reduction in Fel d 1 in the nasal samples after air filtration was 65%, which was less than previously observed with stationary sampling and no activity in the room [8]. In our study, Fel d 1 was detected in all but one nasal sample, probably due to the investigator's vigorous activities, and a lower LOD of FEIA, in comparison to previous ELISA performed (although principally based on the same monoclonal antibodies [21], our amplified FEIA had a LOD of 0.01 ng/ml

Table 2 Correlation coefficients (Pearson correlation of log-transformed values) between dust and different allergens in all personal (1), stationary (2) and nasal (3) samples ($n=30$)

1. Personal samples	Dust (mg/m ³)	Domestic mite allergens (ng/m ³)	Fel d 1 (ng/m ³)	Can f 1 (ng/m ³)
Dust (mg/m ³)	–	0.626	0.909	0.829
Domestic mite allergens (ng/m ³)	–	–	0.645	0.797
Fel d 1 (ng/m ³)	–	–	–	0.791
2. Stationary samples	Dust (mg/m ³)	Domestic mite allergens (ng/m ³)	Fel d 1 (ng/m ³)	Can f 1 (ng/m ³)
Dust (mg/m ³)	–	0.715	0.846	0.690
Domestic mite allergens (ng/m ³)	–	–	0.738	0.824
Fel d 1 (ng/m ³)	–	–	–	0.703
3. Nasal samples	Dust (mg/m ³)	Domestic mite allergens (ng/filter)	Fel d 1 (ng/filter)	Can f 1 (ng/filter)
Domestic mite allergens (ng/filter)	–	–	0.668	0.717
Fel d 1 (ng/filter)	–	–	–	0.683

Table 3 Correlation coefficients for allergen results obtained by parallel personal, stationary or nasal sampling

		Personal samples	Stationary samples	Nasal samples
Personal samples	Domestic mite allergens	–	0.765	0.717
	Fel d 1	–	0.869	0.784
	Can f 1	–	0.860	0.699
Stationary samples	Domestic mite allergens	–	–	0.698
	Fel d 1	–	–	0.629
	Can f 1	–	–	0.714

Fel d 1). However, Fel d 1 concentrations did not differ significantly with or without the AP although a 60% lower median value indicated an effect of air filtration.

Even with air filtration, the airborne allergen concentrations during household chores were rather high (maximal personal values 65 ng/m³ Fel d 1 and 57 ng/m³ Can f 1, maximal stationary values 9 ng/m³ Fel d 1 and 23 ng/m³ Can f 1) compared to previous stationary measurements (maximal values 38 ng/m³ Fel d 1 [8] and 99 ng/m³ Can f 1 [18], adjusted with conversion factors for calibration of multiallergen standard [20] to 11 ng/m³ Fel d 1 and 17 ng/m³ Can f 1), although no cat or dog was present during our measurements. This also applies to airborne DM allergen concentrations during vigorous household chores. The maximal personal airborne DM concentration in the presence of air filtration (319 ng/m³) was eight times higher than the maximal value measured in personal samples collected from living areas (38.6 ng/m³) in a previous study [14]. Our measurements clearly show that peak allergen exposure can occur during intensive housework, including sweeping, vacuuming, dusting, tidying up and moving pillows and blankets, and cannot be prevented by an AP alone. Therefore, not being in the same room when such household chores are performed may be an important preventive measure which has not yet been investigated in intervention studies [22]. Although such a measure is impossible to perform blind, and consequently not studied in placebo-controlled in-

tervention studies, it may be a relevant confounding variable which should be considered. It is very likely that some allergic individuals avoid doing housework or avoid being present during household chores while others do not.

According to Leas et al. [22], the evidence base on allergen reduction intervention for patients with asthma is not sufficient to support meaningful conclusions about the effectiveness of many widely used strategies. Multicomponent strategies like the ones used in the Inner-City Asthma study [23] performed better than single interventions, but further research is needed that includes enough patients to detect clinically meaningful improvements in validated asthma outcomes [22].

Intervention studies should include modern devices for air filtration, and either avoidance or documenting one's presence in a room when household chores are performed. Furthermore, as a secondary outcome, it is recommended to measure allergen concentrations in airborne dust. Repeated measurements or long sampling times, as well as easy-to-use passive sampling methods, such as electrostatic dust collectors, may be helpful when attempting to deal with the high variance of airborne allergen exposure.

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