

Original article

High-efficiency vacuum cleaners increase personal mite allergen exposure, but only slightly

Background: High-efficiency particulate-arrest-filter vacuum cleaners are recommended to allergy sufferers although their use increases personal cat allergen exposure. We aimed to measure personal mite allergen exposure during vacuum cleaning by nasal air sampling and to compare exposures while vacuuming and emptying the vacuum cleaner bag.

Methods: Five brand new high-efficiency vacuum cleaners were selected. An old, previously used vacuum cleaner with its original microfilter *in situ* was used as a control. Nasal air samples were taken prior to and during vacuum cleaning in 10 homes. Samples were processed by HALOgen assay. Personal mite and cat allergen exposure was measured as the dust compartments were emptied.

Results: There was an increase in personal mite allergen exposure with vacuum cleaning, which approached significance ($P = 0.058$). There was no difference between the high-efficiency vacuum cleaners and the control vacuum cleaner ($P = 0.141$). When the dust compartments were emptied, personal mite and cat allergen exposure increased ($P < 0.02$).

Conclusions. The increase in personal mite allergen exposure while vacuum cleaning in an area with mild to moderate mite allergen exposure is small. High-efficiency vacuum cleaners confer no benefit and cannot currently be recommended to allergy sufferers as a means of reducing personal mite allergen exposure.

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Regular vacuum cleaning is recommended to allergy sufferers as a means of reducing the concentrations of domestic aeroallergens in carpeted floors (1). Vacuum cleaners incorporating high-efficiency particulate-arrest (HEPA) filters and synthetic or double-bag collection systems are recommended by professional bodies (1) and patient advocacy groups (e.g. British Allergy Foundation; http://www.allergyuk.org/prod_soalist.html). Unlike older designs (2), under experimental conditions these vacuum cleaners do not leak appreciable amounts of either pet (3–5) or mite (6) allergens. However, recent evidence shows that when these machines are used in homes with cats, personal cat allergen (Fel d 1) exposure increases (4, 7).

Mite allergens are airborne on aerodynamically larger particles than cat or dog allergens (8) and for years airborne mite allergen has been detectable only in artificially disturbed conditions by using high-flow pump-driven air samplers or low-flow samplers over long sampling periods. Neither of these approaches can be said to represent personal allergen exposure. Personal allergen exposure can now be measured over short-time periods using the nasal air sampler (NAS). This is a slot-impactor device worn inside both nostrils with an adhesive membrane which is capable of collecting more than

90% of particles over the size of $5 \mu\text{m}$ (9). Captured particles are then probed for specific allergen content by a modified immunoblotting and colorimetric detection technique (10), or eluted from the tapes and subjected to allergen-specific ELISA. We recently used nasal air samples to demonstrate a three to five-fold increase in personal cat allergen exposure when modern vacuum cleaners are used in homes with cats (4).

We aimed to: (a) compare personal mite allergen exposure while using previously unused, new high-efficiency vacuum cleaners with exposure while using a previously-used, non-HEPA vacuum cleaner as a control and (b) measure personal mite and cat allergen exposure while emptying the vacuum cleaner dust compartments.

Methods

Vacuum cleaners

We selected five previously unused, new vacuum cleaners for testing: the upright cleaners Electrolux Ultrasmart Vac Z4870 (Electrolux plc, Luton, UK) and the Hoover Pure Power Pets 1600 (Hoover Ltd, Merthyr Tydfil, UK), the cylinder cleaners Nilfisk GM410 (Nilfisk-Advance Ltd, Bury St Edmonds, UK) and Miele 'The Solution 500' (Miele Company Ltd, Abingdon, UK), and a

water-filter cleaner Stimvak ('Mitevak'; Stimvak Ltd, London, UK). All new vacuum cleaners apart from the water filtration model had integral HEPA filters. During testing, each of these vacuum cleaners was compared with a 10-year old, used 'control' vacuum cleaner (Electrolux Dolphin Superboost 1200W; Electrolux plc) with its original non-HEPA microfilter *in situ*. Vacuum cleaner bags were used as recommended by the manufacturers (either double-thickness paper or synthetic fibre bags).

Field study design

The field study was conducted as part of a wider study which recently reported the effects of vacuum cleaning on personal cat allergen exposure (4). Vacuum cleaners were tested in pairs: each unused, new vacuum cleaner was compared with the control vacuum cleaner. The same two individuals tested five such pairs of vacuum cleaners once each in five homes. Thereafter, a second pair of individuals compared each of these five unused, new vacuum cleaners with the control vacuum cleaner once more, in a further five homes. Vacuum cleaners were tested in a random order in the same room with a 3-day period between the tests (no vacuuming was performed during this period). Each of the two investigators took one baseline 15-min nasal air sample (10, 11) while mimicking vacuum cleaning with the vacuum cleaner switched off and then one 15-min sample taken during the vacuum cleaning. Thus 10 pairs of experiments were performed and 20 NA samples were taken for each experimental condition.

Allergen exposure while emptying the vacuum cleaner

Personal exposure to mite allergen while emptying dust from a vacuum cleaner was measured as follows: after the field samples for allergen exposure had been taken, the vacuum cleaners were emptied of the collected dust into a waste bin in the house in accordance with the manufacturers' instructions. The person emptying the cleaner ('operator') and a bystander standing alongside both wore NAS for 5 min before emptying the cleaner and then while the vacuum cleaner was being emptied. Two individuals randomly assumed the roles of 'operator' and 'bystander'. Unused, new and control vacuum cleaners were compared in the same pairwise manner described above. The control vacuum cleaner used bags, which could not be sealed. The Electrolux, Miele, Nilfisk and Hoover cleaners had bags, which could be sealed before removal. The Stimvak vacuum cleaner was emptied by disposal of the aqueous solution of house dust.

Personal exposure to cat allergen while emptying dust was measured as follows: vacuum cleaners were emptied after the experimental chamber experiments and also after some additional visits to homes with cats. For this purpose, vacuum cleaners were not strictly assessed in test control pairs and therefore the overall effect of emptying vacuum cleaners on cat allergen exposure was examined, rather than differences between the test and control vacuum cleaners. The same two individuals performed nasal air sampling in a manner identical to that described above.

HALOgen assay

Nasal air samples were processed by the HALOgen technique (Inhalix Pty, Sydney, Australia) (10). Each pair of adhesive tapes from the NAS was laminated onto an individual protein-binding membrane and immunostained using the appropriate primary antibody: anti-Der p 1 for the field vacuum cleaning study and the vacuum cleaner emptying experiments; anti-Fel d 1 for the experimental chamber study and some of the vacuum cleaner emptying experiments. Each allergen-bearing particle appeared as a 'halo' of

colour surrounding an inspired particle. Samples were coded. Particles were counted three times using light microscopy (×40) by one experienced observer. The particle units were represented by 'counts' where one count was one observed allergen-bearing particle.

Statistical methods

A power calculation was based on preliminary data for Fel d 1 and the use of five houses. The study was designed to have 92% power with a 5% significance of detecting a 50% difference in allergen exposure between switching the vacuum cleaners on and off and also between the old and new groups of vacuum cleaners. This assumed five houses. Count data were square root transformed for analysis (12). A standard analysis of variance was used (SPSS 9.0; SPSS Inc, Chicago, IL).

Results

Field study: effect of domestic vacuum cleaning on inhaled mite allergen

The effect of switching on the vacuum cleaners approaches significance [$F(1,76) = 3.703, P = 0.058$] (Table 1, Fig. 1). There is no difference between the unused, new and control vacuum cleaners [$F(1,76) = 2.210, P = 0.141$], thus demonstrating that the increase is seen across both new and control vacuum cleaners.

Field study: effect of emptying domestic vacuum cleaners on inhaled cat and mite allergen

Emptying the vacuum cleaners resulted in a significant increase in both mite [$F(1,36) = 6.2, P < 0.02$] and cat [$F(1,21) = 14.1, P < 0.02$] allergen (Table 2, Fig. 2). There was no difference between the control vacuum cleaner and the unused, new models [$F(1,36) = 0.73, P = 0.4$] for mite allergen. There was no difference between the counts for the operator and bystander for either mite allergen [$F(1,36) = 0.05, P > 0.8$] or for cat allergen [$F(1,21) = 0.03, P > 0.8$].

Discussion

There is an increase in personal mite allergen exposure during vacuum cleaning with all vacuum cleaners, which

Table 1. Vacuum cleaning and allergen exposure: Der p 1 bearing particle counts (halo units)

	Der p 1 particle counts, median (range)	
	Baseline	Vacuum cleaning
<i>n</i>	20	20
Control	2 (0–12)	4 (0–32)
New	2 (0–10)	2 (0–10)

Vacuum cleaners are grouped into either control or unused (new). Each value is the median (range) of the observations in each cell (2 observers × 10 homes).

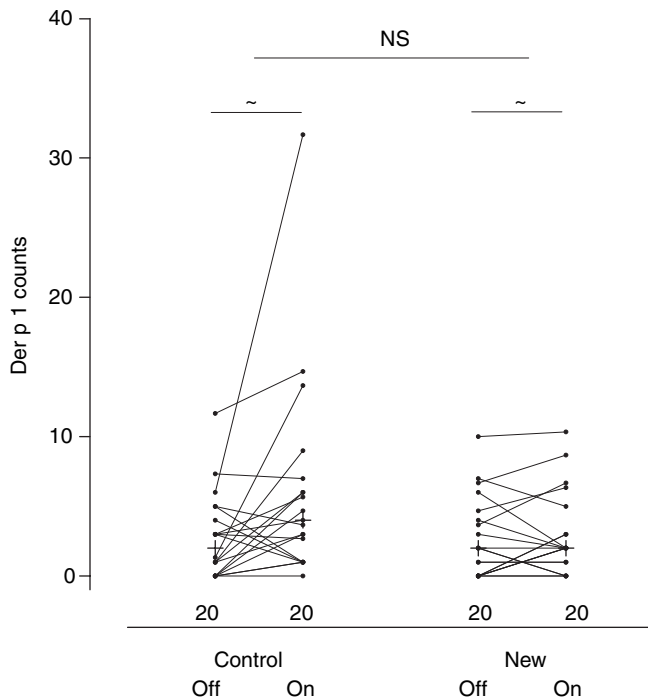


Figure 1. Inhaled mite particle counts during vacuum cleaning. The median count is indicated by +. NS, not significant ($P > 0.1$). $\sim P = 0.058$.

approaches significance. We previously tested these same vacuum cleaners in an experimental chamber (4): none of the unused, new vacuum cleaners leaked test allergen, while the control vacuum cleaner did. Therefore leaky seals and dust compartments are not the cause of the increase in exposure. We propose that the increase is caused by the agitation of the carpet dust reservoirs by the back and forth motion of the vacuum cleaner with its operator and, for upright cleaners, the action of the beating-bar. Further support for this argument comes from a recent comparison of central vacuum cleaners with regular vacuum cleaners (13). Central vacuum cleaners have their dust and exhaust ducted away from the site of collection into a sealed compartment elsewhere on the premises. Increases in allergen exposure caused by this method of vacuum cleaning must therefore be due to the

actions of the cleaning head with its operator on the carpet. Indeed, the study showed that both groups of vacuum cleaners resulted in equivalent airborne dust and Fel d 1 concentrations.

The numbers of mite allergen-bearing particles are much lower than we have previously demonstrated for cat allergen (4) and the magnitude of the increase with switching on the vacuum cleaner is much smaller. This is presumably because mite-bearing particles are aerodynamically larger than those bearing pet allergens. Consequently, they either settle quickly (8, 14) or are less prone to re-dispersal by the sweeping mechanism.

Earlier studies of airborne mite allergen exposure in homes used either high-flow fixed-position air samplers, or low-flow lapel-mounted samplers. Under undisturbed conditions, mite allergen levels were completely undetectable (8, 14, 15). Under conditions of light activity or sleep, mite allergen was detectable, but required the sampling of hundreds (16) to several thousands of litres of air (17–19). Studies using smaller sampling volumes failed to detect mite allergen (20). Two previous studies used these methods to demonstrate an increase in airborne mite allergen exposure during vacuum cleaning when cleaners without any integral air filter were used. The use of HEPA-filter vacuum cleaners resulted in less exposure (21, 22). We demonstrated no difference in mite allergen exposure between our control vacuum cleaners and the unused, new group. This discrepancy may be due to differences between the control machines in the different studies: our control vacuum cleaner did have a filter in place. Although this non-HEPA filter was years past its replacement date, the use of such a vacuum cleaner as a control may have diminished any difference in mite exposure between the control and unused, new groups. However, our control machine did leak test allergen in the experimental chamber and its design better reflects vacuum cleaners at the cheaper end of today's market than the vacuum cleaners used in older studies. It is therefore an appropriate choice of control.

It is impossible to compare exposures from different vacuum cleaner studies, which use different methodologies. The volume of air sampled in the study using low-flow lapel-mounted samplers (22) was one-sixtieth of the volume of air sampled in the study using fixed-position

Table 2. Cat and mite allergen inhalation while emptying a vacuum cleaner: Der p 1 and Fel d 1 bearing particle counts (halo units)

Fel d 1 particle counts, median (range)				Der p 1 particle counts, median (range)				
	<i>n</i>	Baseline	Emptying	<i>n</i>	Control		New	
					Baseline	Emptying	Baseline	Emptying
Operator	6	0 (0–3)	29 (0–94)	5	0 (0–0)	2 (0–11)	2 (0–2)	0 (0–10)
Bystander	6	2 (0–2)	17 (1–154)	5	0 (0–1)	2 (0–27)	0 (0–1)	0 (0–7)
Combined	12	1 (0–3)	25 (0–154)	10	0 (0–1)	2 (0–27)	1 (0–2)	0 (0–10)

Each value is the median (range) of the observations in each cell. 'Operator' refers to the inhaled allergen particle count of the individual emptying the dust compartment. 'Bystander' refers to the inhaled allergen particle count of the individual standing close-by.

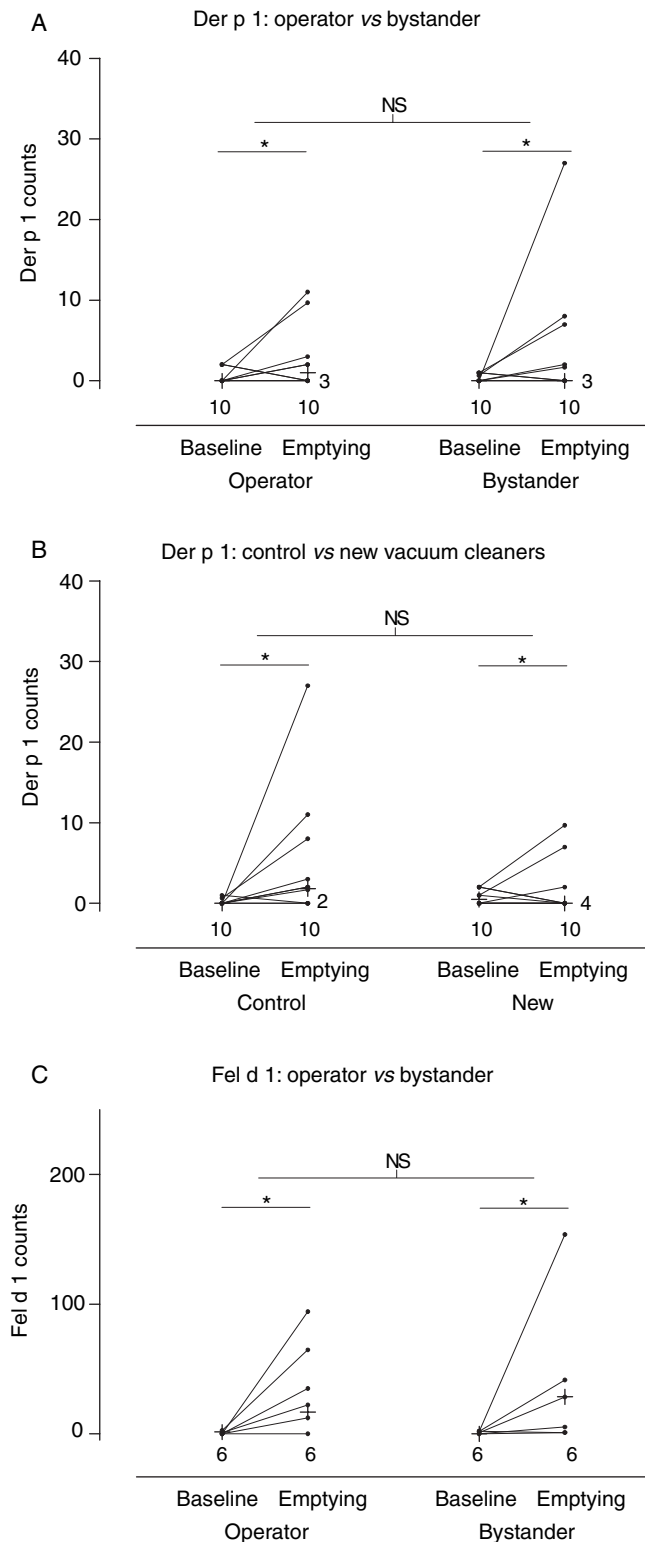


Figure 2. Inhaled mite (A, B) and cat (C) particle counts while emptying vacuum cleaners. The median count is indicated by +. NS, not significant ($P \geq 0.05$). * $P < 0.02$. Numbers next to the lowest counts refer to the number of pairs of zero-zero counts. Sample numbers refer to the number of nasal air samples for each condition.

high flow samplers (21), yet the total Der p 1 collected in both studies is of the same order of magnitude. Neither method is likely to bear a close relationship to mite allergen exposure as it occurs at the naso-respiratory mucosa. In contrast, the NAS collects directly inspired particles and detects changes in mite allergen concentration in the breathing zone, such as those caused by a change of clothing (10). It is therefore a useful tool for studying the effect of a change in environmental conditions on personal allergen exposure.

The numbers of mite-bearing particles detected while emptying dust compartments were higher than those detected while vacuum cleaning. The new high-efficiency vacuum cleaners had either double-bag or synthetic impermeable bag systems, sealed by the user before removal. However, sealing these bags produced a small cloud of dust. This is not likely to represent significant cumulative allergen load, yet in some occupational circumstances, such exposure may be important.

Does prolonged use of HEPA-filter vacuum cleaners result in a reduction in mite allergen exposure? Several short-term studies have demonstrated reductions in carpet mite allergen concentrations. In an area with high endemic mite allergen levels, Vojta *et al.* (23) showed that a single session of intensive vacuum cleaning with steam cleaning could result in a transient reduction to levels below the $10 \mu\text{g/g}$ threshold associated with symptom exacerbation (24). Two further short-term studies demonstrated some reduction in carpet mite allergen concentrations (25, 26). Arlian *et al.* (27) observed that in homes with dry conditions maintained by dehumidification with air conditioning, mite allergen concentrations fell to levels almost below the $2 \mu\text{g/g}$ threshold associated with sensitization. This presumably reflects clearance of allergens and dead mites by carpet/floor cleaning. However, long-term trials have not confirmed any beneficial effect of high-efficiency vacuum cleaning on reservoir mite levels (28, 29) and no data exist for the effects on personal mite exposure. Attaining such a measure may help determine whether further long-term trials are worthwhile.

We can extrapolate our data to estimate the personal annual mite exposure caused by vacuum cleaning; assuming that a mite faecal pellet contains around 0.1 ng of Der p 1 (30) and that an individual vacuums once weekly for 15 min, the annual exposure attributable to vacuum cleaning in UK would be around 10 ng of Der p 1, 100–200-fold lower than the annual exposure because of lying in bed, estimated by nasal sampling (31). As the NAS will collect a greater proportion of the larger mite allergen-bearing particles than cat allergen-bearing particles (9), we conclude that during vacuum cleaning, personal exposure to Fel d 1 is greater than exposure to Der p 1. Furthermore, exposure to Der p 1 from other domestic sources such as lying in bed is much greater than from vacuum cleaning.

At present, high-efficiency vacuum cleaners cannot be specifically recommended to allergy sufferers on

the premise that their use will reduce personal mite allergen exposure during vacuum cleaning. They cannot therefore be claimed to reduce allergic symptoms.

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