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How clean is your house? A study of house dust mites, allergens and other contents of dust samples collected from households

Lucy S. Casley^a, Tom Godec^b, James G. Logan^{a,c}, James C. Pearce^a, Hugh M. P. Smith^a, Sophie A. Stewart^a  and Sarah Y. Dewhirst^a

^aArthropod Control Product Test Centre (*arctec*), London School of Hygiene and Tropical Medicine, London, United Kingdom; ^bDepartment of Medical Statistics, London School of Hygiene and Tropical Medicine, London, United Kingdom; ^cDepartment of Disease Control, London School of Hygiene and Tropical Medicine, London, United Kingdom

ABSTRACT

Household dust contains an array of constituents, including house dust mites (HDM) and the HDM allergen, *Der p 1*, which can cause sensitivities such as asthma and eczema. Vacuuming can help alleviate symptoms, yet little is understood about cleaning behaviour in different households. This pilot study investigated the contents of dust from four household types (students; over 65 s; and families with and without pets). This was then related to cleaning behaviours and perceptions of cleanliness. Our investigation found that HDMs and *Der p 1* were present in all households and sampling locations, including participants' cars. The median *Der p 1* was greatest in the living room, though results varied. Demographic group was a determinant for the number of human and pet hairs present in dust. Surprisingly, vacuuming was the most disliked task overall. This information requires consideration when developing cleaning products and advising individuals with dust-related health issues.

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KEYWORDS

House dust mite; household cleaning behaviour; dust sample collection; hygiene survey; *Der p 1* allergen

Introduction

The contents of household dust is highly variable and a range of constituents have been reported throughout the home, including dander, food matter, arthropods, hairs, chemicals, heavy metals, bacteria, fungi and mold (Zahradnik E. and Raulf M. 2014; Barberan et al. 2015; Amaro et al. 2016). Household dust is considered to be an important reservoir of indoor allergens, including those from cats, dogs and mites (Warner et al. 1990; Colloff et al. 1992; Zahradnik and Raulf 2014). Cat and dog allergens are not only present in the dander and hair from cats and dogs, but are also ubiquitous in the environments where these animals are present, even where you might not expect to find them, such as human hair (Siebers et al. 1998; Karlsson and Renstrom 2005; Liccardi et al. 2005; Krop et al. 2007). One of the most prevalent and clinically important source of indoor allergens comes from the scales and faecal pellets of various mite species (Erwin et al. 2005; Platts-Mills 2007; Zahradnik and Raulf 2014; Sanchez-Borges et al. 2017). *Dermatophagoides pteronyssinus* is an abundant house dust mite species found in houses in temperate regions (Arlian and Morgan 2003; Zock et al. 2006). This species releases high titres of the allergen *Der p 1* into the environment, with particularly high levels where you find their main food source (human skin and fungi) (Zock et al. 2006). The optimal conditions for house dust mites are warm, moist locations and house dust mites have been observed in various locations within the car and

home, such as children's car seats, mattresses, pillows, carpets, sofas and soft toys (Binotti et al. 2005; Sun et al. 2014; Clarke et al. 2015b). The presence of other species of dust mites (Acari: Pyroglyphidae), storage mites (Acari: Acaridae, Glycyphagidae, Chortoglyphidae, Aeroglyphidae) and predatory mites (Acari: Cheyletidae) have also been reported in household dust, whereas *D. pteronyssinus* almost exclusively inhabits household dust (Arlian and Platts-Mills 2001; Arlian and Morgan 2003).

Sensitization to allergens, particularly during childhood, can lead to the development of inflammatory diseases, including perennial allergic rhinitis and eczema and are also a significant risk factor for asthma (Sanchez-Borges et al. 2017). It has been reported that these dust-related diseases affect approximately 15–20% of the population in industrialized countries (Zock et al. 2006; Jacquet 2013). While regular vacuuming can help to alleviate symptoms of dust-related diseases (Wu et al. 2012), not all households practice regular vacuuming of their mattresses and the frequency of vacuuming in other locations is not well documented (Platts-Mills et al. 1997). Several studies successfully used surveys as a method to investigate whether housing characteristics, such as age and ventilation, were predictors of *Der p 1* levels in mattresses (Arbes et al. 2003; Garrett et al. 1998; Zock et al. 2006; Portnoy et al. 2013). These studies have compared allergen levels geographically across European countries, and nationally in America and Australia. In particular, these studies have focused on one demographic group, such as families, and there are currently no national studies investigating differences between dust content across other demographics in our society. In addition, Zock et al. (2006) recommended that future studies include allergen assessment at multiple household locations including carpets and upholstered furniture.

The aim of this pilot study was to identify the contents of dust collected from each participants' car and six locations within their home, and relate this to the participants' reported cleaning behaviour and perceptions of cleanliness. This was achieved by analysing dust samples collected from multiple locations for each demographic group: families with pets; families without pets; students without pets; and over 65 s without pets. A survey was completed by each participant (a single member of each household) to collect data on cleaning behaviour and perceptions of cleanliness. The results of this study may assist in the development of better cleaning products and interventions for removal of allergens, re-evaluate the way such products are developed or marketed, and better inform individuals with dust-related health issues.

Materials and methods

Ethical statement

Before the study commenced, full approval was obtained from the London School of Hygiene and Tropical Medicine's (LSHTM) Research Ethics Committee (approval number 11,796) on 3 October 2016. All participants completed an eligibility questionnaire, provided written informed consent and retained a copy of the Participant Information Sheet. As this pilot study was purely observational, the protocol was not registered in an International Committee of Medical Journal Editors-approved publicly accessible registry.

Trial design

House dust samples were collected from four demographic groups: families with pets, families without pets, students without pets and the over 65 s without pets. The following key criteria had to be met in order to be enrolled into one of the four demographics: families – at least one child under the age of 12; students – all members of the household in full time education; over 65 s – all members of the household over the age of 65 years; with pets – at least one pet that was a bird or mammal; without pets – no bird or mammal pets. Households which included a resident with severe-dust related health conditions were excluded from taking part.

This study was conducted during October 2016 through to January 2017 in London, UK. A total of 40 participants, 10 from each demographic, were recruited via an email to the staff of the London School of Hygiene and Tropical Medicine. A single participant representing their household was asked to complete a survey and collect samples from; (1) their car; (2) the living room carpet, (3) the mattress in the master bedroom; (4) the sofa; (5) a top surface – of a wardrobe, drawers or high shelf. All sampling locations had to be at least 6 months old, not treated with an acaricide product in the last 12 months, and the mattresses had to have no anti-allergy mattress protectors fitted. Participants in the ‘family’ groups (both with and without pets) were also asked to collect samples from; (6) a mattress in a child’s bedroom and (7) a child’s soft toy.

House dust-collection method

Participants were sent a standardized pack for dust collection. This pack contained a cord-free Dyson V8 Animal vacuum, a dust-collecting device, templates, pre-labelled sample dishes and bags, full written instructions and a short video demonstrating the dust-collection method to minimize differences between collection techniques. The dust-collecting device was the DUSTREAM® Collector (DU-ST-1, Indoor Biotechnologies Inc., Cardiff, UK) and consisted of a collector and a nylon filter. The nylon filter was inserted into the collector, which was then fitted onto the vacuum cleaner. This design was key as it prevented any contamination of the sample and did not require the participant to manipulate the sample in any way. All participants were asked not to vacuum the sampling locations for 2 weeks prior to sample collection, and all soft furnishing had to be at least 6 months old to ensure sufficient quantities of dust were available for analysis. Mattresses included in the study were slept on at least five nights per week.

Participants were asked to vacuum within a 50 cm × 50 cm template provided, for 2–3 min to ensure the same total of area was sampled for the living room carpet, sofa and mattresses. Templates were not used for dust sample collection from the car, top surface or soft toy. Participants were asked to collect these samples as described in the following text:

- (1) Car – the driver’s seat, the foot well in front of the driver’s seat, and the seat at the back of the car (frequently sat on) for 30–45 s each, covering as much area as possible. Participants were then asked to vacuum the dashboard or gearstick, both for 15–20 s, covering as much area as possible;
- (2) Living room carpet – the area immediately in front of a frequently used sofa, in areas that are not vacuumed regularly (e.g. underneath the sofa) and particularly dusty areas;
- (3) Master bedroom mattress – the pillow end of the mattress in an area where someone usually sleeps, any buttons and folds on the mattress, and any particularly dusty areas;
- (4) Sofa – seat cushions, under seat cushions, buttons, folds and particularly dust areas;
- (5) Top surface – the template was not used and participants were asked to vacuum as much of the location as possible within the set time period;
- (6) Child’s mattress (families only) – the pillow end of the mattress in an area where someone usually sleeps, any buttons and folds on the mattress, and any particularly dusty areas;
- (7) Child’s soft toy (families only) – the template was not used and participants were asked to vacuum as much of the toy as possible within the set time period. The soft toy had to be at least 25 cm x 25 cm in size.

After each sample was collected, participants were asked to remove the nylon filter, place a ‘stopper’ (white rubber septa, 1.3 mm, Sigma Aldrich, UK) on the end of the filter to prevent spillage of dust, and place it into a labelled plastic petri dish (Ø 55 mm, Thermo Scientific, UK), with the lid taped down securely. The petri dish was placed into a sealable plastic bag with

dampened cotton wool to preserve live dust mites. Once all samples had been collected, participants were asked to return the samples to the investigators by post or in person within 24 h.

Sample processing

Samples were processed within 24 h of receiving them. The whole dust sample was weighed and then sieved (mesh size 2 mm) to separate the large debris from the fine dust. The weight of the large debris and sieved dust was recorded, and their content was observed using a dissecting microscope (Nikon, up to 40× magnification) and recorded. Where the volume of the sample was sufficient, at least 10 mg of the sieved dust was sub-sampled and stored at 4°C for subsequent enzyme-linked immunosorbent assays (ELISA), a sensitive test for *D. pteronyssinus* allergen, *Der p 1*. The remaining sieved dust was used for house dust mite quantification.

Der p 1 allergen quantification

Der p 1 allergens were quantified using monoclonal antibody ELISAs (Indoor Biotechnologies Inc., Cardiff, UK), according to the manufacturer's instructions, and reported in ng of allergen per mg of sieved dust (limit of detection 0.78 ng/mL). At least 10 mg of fine dust was required to conduct ELISA testing, and as some samples contained less than this, not all samples were analysed.

Mite quantification

The number and type of dead and live mites was counted using a dissecting microscope (Nikon, up to 40× magnification). If the sieved dust samples weighed more than 100 mg, mites were recovered following a technique published by Cameron & Hill (Cameron and Hill 2002). Each fine dust sample (100 mg) was placed in a 50 mL polypropylene beaker (Azlon Plastics, UK) containing 45 mL of tap water and covered with Parafilm M (Bemis, UK). The beaker was inverted 20 times, and the Parafilm removed. The beaker was placed in a freezer at −20°C for 1 h and 15 min, forming three layers of ice within the beaker. The thin, top layer of ice contained mites that had floated to the surface. The middle layer remained unfrozen with some dust debris, and the bottom layer contained ice and dust debris. The top layer of ice was gently removed from the beaker with forceps and a spatula, and placed in the lid of a petri dish (Ø 55 mm, Thermo Scientific, UK), marked with gridlines for observation purposes. Once the ice had melted, the sample was examined using a dissecting microscope at 30× magnification. The number and type of dead and live mites was recorded: dust mites (house); other mites; and type not determined (TND).

Hair analysis

Any hairs found in the dust samples were mounted onto microscope slides with DPX mounting medium (Fisher Chemical, UK), and analysed using a Leica DMRB microscope with a Retiga 2000 R fast 1394 camera from Q imaging. Volocity software (Perkin Elmer) was used to acquire the images. Morphological features of the hairs were observed and hairs were categorized as 'human' (Ogle Jr and Fox 1998), 'cat', 'dog' or 'other' animal (Moore 1988; Linacre 2009; Bailey 2016), and the total number of each hair type was recorded for every sample.

Survey

A structured, self-administered questionnaire survey, using both closed and open-ended questions, was developed to investigate perceptions of household cleanliness, frequency of cleaning and attitude towards cleaning. The survey was completed by every enrolled participant (an individual within the household) before collecting dust samples.

The questionnaire survey consisted of 28 questions covering four themes: (1) resident information (including total number, age ranges, allergies and pets); (2) cleaning behaviour (gender of individual(s) responsible for cleaning, frequency of cleaning and vacuuming); (3) perception of cleanliness (cleanest and least clean areas of the car and home, and areas cleaned the most and least) and (4) attitudes towards cleaning (such as most disliked cleaning tasks and difficult areas to vacuum). All factors relating to demographics were cross referenced to questions under themes 2–4.

Statistical analysis

Results from ELISA tests were compared between demographic groups for all locations using a non-parametric quality-of-medians Chi-squared test, reporting p values. Medians (interquartile ranges [IQR]) for each category rather than means and standard deviation were presented due to the data being right skewed, and containing a large number of zero values, making it hard to transform the data suitably in order to perform a parametric test. Median concentrations were compared by demographic group and this was repeated by location over all demographic groups combined (only between master bedroom mattress, living room carpet, sofa and car).

Weight of dust was compared between demographic groups for all locations using a non-parametric quality-of-medians Chi-squared test, reporting p values. Medians (interquartile ranges [IQR]) for each category rather than means and standard deviation were presented due to the data being right skewed. These comparisons were also conducted by total weight of dust summed across all locations by demographic group, once excluding locations of child's mattress and child's soft toy as these were only applicable to family demographics, and repeated summing over all locations for the family demographic groups.

Types of content found in collected samples were compared using Chi-Squared tests comparing counts of content present in different samples by demographic group. This was done for all samples across all locations and also separately, split by location. In addition, counts of content present in different samples, were also compared by location for all samples, regardless of the demographic.

Relative incidence rate ratios (95% CI) were estimated comparing the incidence rates between demographic groups for number of pet hairs, and number of human hairs, found at each location, using a general negative binomial model. The p values were also presented. This analysis was also conducted for total numbers of pet hairs, or human hairs, found summed across all locations by demographic group, once excluding locations of child's mattress and child's soft toy as these were only applicable to family demographics, and repeated summing over all locations for the family demographic groups.

Relative incidence rate ratios (95% CI) were estimated comparing the incidence rates of mites between demographic groups, and repeated between locations, using negative binomial models. Global p values for the effect of demographic group and also location were presented. Relative incidence rate ratios (95% CI) were estimated comparing the incidence rates of number of people per household between demographic groups using a Poisson model for count data. Global p values were presented. Relative incidence rate ratios (95% CI) were estimated comparing the incidence rates between demographic groups for frequency of cleaning, using a general negative binomial model. The p values were also presented.

Results

Dust samples

All 40 participants returned the complete set of dust samples they were asked to collect (seven locations for families with pets and families without pets, five locations for students without pets and over 65 s without pets), meaning a total of 240 samples were received.

Der p 1 allergen quantification

The allergen *Der p 1* was detected in all collection locations from all households (Figure 1). Although the samples from Students' homes contained the least *Der p 1*, this difference was not significant ($p = 0.059$). In terms of location in the home, the most *Der p 1* was found in the living room carpet and sofa, followed by the master bedroom mattress and the least *Der p 1* was found in the car ($p < 0.05$). *Der p 1* collected from top surface (median 641 ng/g (IQR 256–933)), child's mattress (median 138 ng/g (IQR 31–931)) and child's soft toy (median 115 ng/g (IQR 9–752)) was not included in the statistical analysis as fewer than half of the samples were analysed due to insufficient amount of dust collected from these locations.

Weight of dust samples. The most dust was collected from the families without pets households (median sum sample weight = 2005 mg (IQR 1570–2450)), followed by the student, families with pets and over 65 s households (1200 mg (IQR 600–2070); 1005 mg (IQR 350–3600); 805 mg (IQR 570–1950), respectively), though this difference was not significant ($p = 0.187$).

(Figure 2) shows the median weights of dust collected by the different household types from the various locations in the home as well as the car. There was a significant difference in dust quantity in the car between household types ($p = 0.022$); a greater weight of dust was collected from cars belonging to families, but particularly the families without pets compared to students without pets and over 65's without pets (Figure 2). No significant differences in the median weight of dust was observed between the household types at the other sampling locations (master bedroom mattress: $p = 0.750$, living room carpet: $p = 0.261$, top surface: $p = 0.076$, sofa: $p = 0.439$, child mattress: 0.655, child soft toy: $p = 0.187$), though the quantity of dust collected from the student living room carpet was greater than other groups.

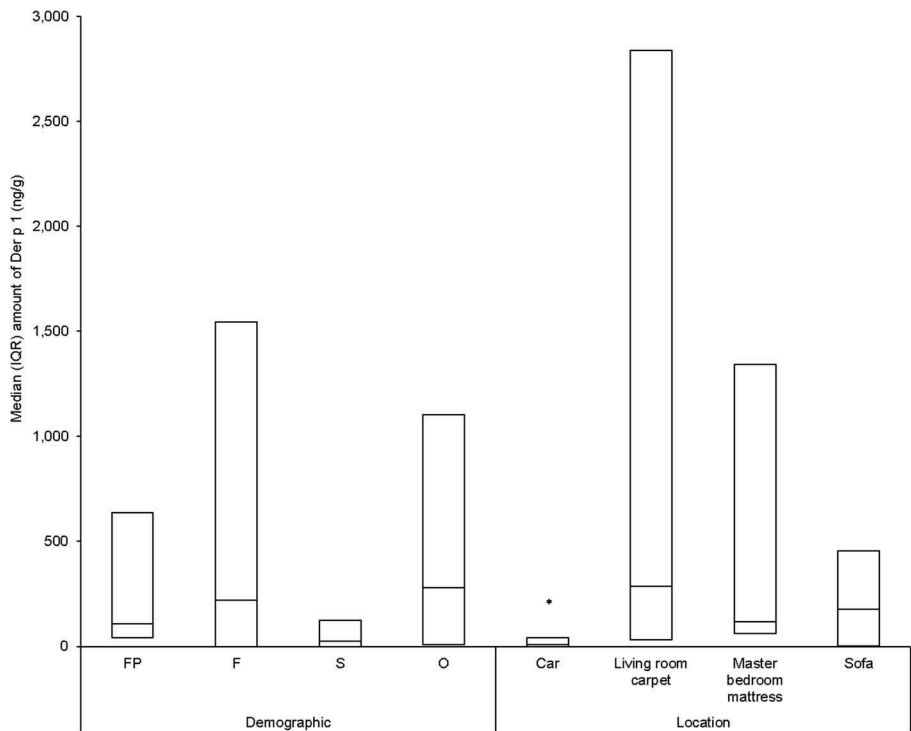


Figure 1. The median (IQR) amount of *Der p 1* in dust samples collected from participant households. Asterisk denotes significant difference ($p < 0.05$) to the master bedroom mattress. FP = families with pets, F = families without pets, S = students without pets, O = over 65s without pets.

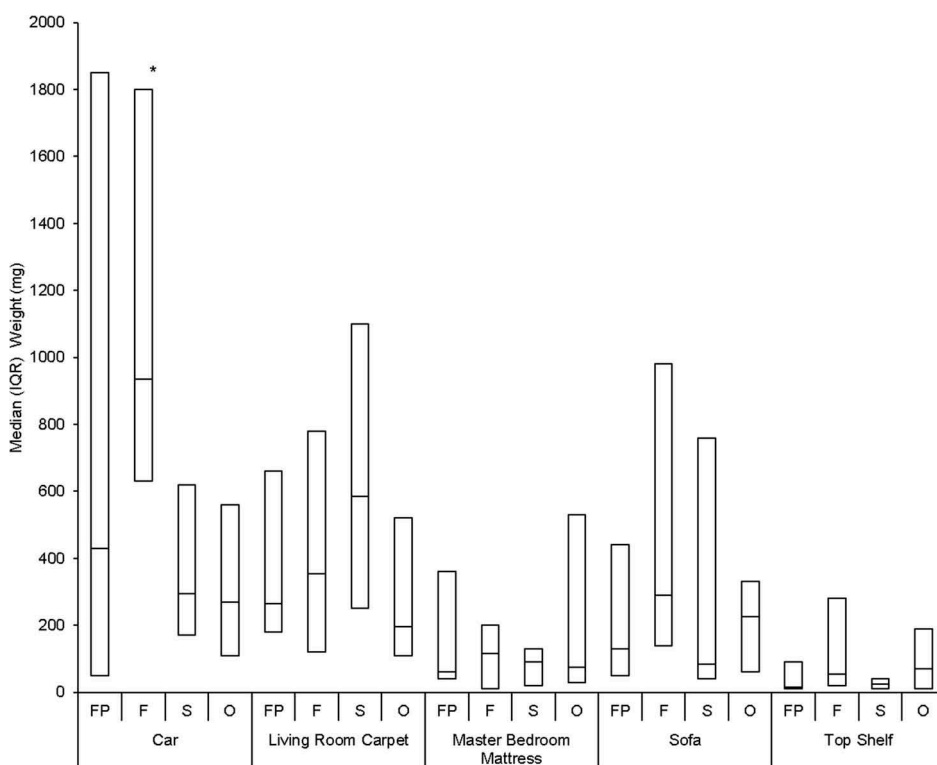


Figure 2. The median (IQR) weight of dust collected from sampling locations within participating households. (A) Five sampling locations, (B) two sampling locations exclusive to families with pets and families without pets. Asterisk denotes significant difference ($p < 0.05$) between other demographic groups within the set location. FP = families with pets, F = families without pets, S = students without pets, O = over 65s without pets.

Contents of dust samples. The most common constituents of dust collected (excluding the child's mattress and child's toy), were fibres (present in 97.5% of samples), hairs (present in 74.5% of samples), and skin cells (present in 68.5% of samples) (Table 1). Significantly fewer samples containing hairs were collected from the over 65 s compared to the other three demographic groups, and the greatest percentage of samples containing hairs were from the car and the sofa. Fewer dust samples from the car contained skin cells compared with other locations. Items that were found in less than 5% of all samples collected included an animal claw, faeces, foam, foil, glass, paint, paper, plastic, polystyrene, rubber, sand, scab and stickers (data not shown). Other than hairs, no significant differences in identified dust contents between demographic groups was observed.

With regards to the location within the home, however, there were some significant differences in dust contents (Table 1). More samples from the living room carpet and sofa contained food matter. Glitter was located in all locations apart from the master bedroom mattress. A higher percentage of samples from the car and living room carpet contained plant material and stones compared to the other locations. Samples from the car also had the highest percentage of samples containing soil. Toe nails were only located in the samples from the living room carpet and the sofa. No significant differences were seen between location and percentage of samples containing insects and mites.

Fibres (100% of samples), skin cells (85% of samples) and hairs (77.5% of samples) were the most common constituent collected from the child's mattress and child's toy. A low percentage of samples from the child's mattress also contained feathers (5%), food matter (25%), glitter (10%), insects (5%), mites (20%) and plant material (20%). Also a low percentage of samples from the child's toy contained food matter (10%), mites (15%) and plant material (5%).

Table 1. The percentage of dust samples containing identified contents from all sampling locations.

Group	Feathers	Fibres	Food matter	Glitter	Hairs ^A	Insects ^B	Mites ^C	Plant material	Skin cells	Soil	Stones	Toe nails
All	7	97.5	34.5	14	74.5	7.5	10	52.5	68.5	16.5	34	6.5
Demographic group												
FP	8	96	42	16	84	14	18	58	58	12	28	4
F	12	98	36	10	74	4	12	52	62	20	26	8
S	2	100	36	10	80	4	6	52	78	16	48	12
O	6	96	24	20	60	8	4	48	76	18	34	2
P-value	0.262	0.521	0.286	0.393	0.033	0.185	0.083	0.796	0.074	0.736	0.086	0.183
Location												
Car	7.5	95	12.5	25	92.5	7.5	10	100	17.5	77.5	92.5	0
Living room carpet	7.5	97.5	75	17.5	87.5	15	15	82.5	87.5	0	55	17.5
Master bedroom mattress	2.5	97.5	2.5	0	65	0	10	10	92.5	2.5	5	0
Sofa	17.5	100	77.5	20	92.5	5	10	52.5	75	0	15	15
Top surface	2.5	97.5	2.5	7.5	35	10	5	17.5	70	2.5	2.5	0
P-value	0.049	0.728	<0.001	0.009	<0.001	0.125	0.695	<0.001	<0.001	<0.001	<0.001	<0.001

FP = Families with pets, F = Families without pets, S = Students without pets, O = Over 65 s without pets, ^A human, pet and other hairs, ^B insects include live, dead and parts, ^C mites include house dust, other and type not determined.

Mite quantification. Overall, 11.25% of samples contained mites across all seven sampling locations. House dust mites were present in 10.0% of all dust samples and were found across all demographic groups and sampling locations. Other unidentified mites were present in 6.6% of all samples and were found in all demographic groups and sampling locations, except for the child's soft toy.

House dust mites were collected from 32.5% of households (4 out of 10 families with pets, 5 out of 10 families without pets, 2 out of 10 student homes and 1 out of 10 over 65 s households). No significant difference ($p = 0.407$) was detected between the demographic groups and the mean number of dust mites per gram of dust collected (families with pets: 5.75, S.E. 5.29, families without pets: 2.51, S.E. 2.35, students without pets: 0.43, S.E. 0.44 and over 65 s without pets: 1.92, S.E. 1.80).

Only 2.5–10% of samples collected from each location contained house dust mites (Car: 5%, Living room carpet: 15%, Master bedroom mattress: 10%, Sofa: 10%, Top Shelf: 2.5%, child's mattress: 10%, child's toy: 7.5%). No significant difference ($p = 0.671$) occurred between the demographic groups and the mean number of dust mites per gram of dust collected (car: 1.25, S.E. 1.42, living room carpet: 3.57, S.E. 4.03, master bedroom mattress: 2.95, S.E. 3.34, sofa: 5.08, S.E. 5.73, top shelf: 0.40, S.E. 0.46). House dust mites were also collected from the child's mattress (1.26, S.E. 0.66,) and the child's toy (0.50 ± 0.29).

Hair analysis. Overall, 71.7% of samples contained human hairs across all seven sampling locations. Significantly ($p < 0.001$) fewer human hairs were collected from over 65 s without pets (16.30, S.E. 2.97) compared to families with pets (41.80, S.E. 2.97), families without pets (31.70, S.E. 5.52) and students without pets (36.30, S.E. 6.28), excluding hairs from the child's mattress and toy. Significantly ($p = 0.001$) more human hairs were collected from the master bedroom mattress from the families with pets households (9.20, S.E. 3.16) than the families without pets (1.30, S.E. 0.56), students without pets (3.80, S.E. 1.39) and the over 65 s without pets (1.10, S.E. 0.49). There was no significant difference between the different demographic groups and the number of human hairs present at the remaining sampling locations (living room carpet: $p = 0.233$, top surface: $p = 0.284$, sofa: $p = 0.513$, car: $p = 0.421$, child mattress: $p = 0.948$, child toy: $p = 0.690$).

Over a third (38.6%) of samples collected from families with pets contained cat, dog or other animal hairs and were observed across all sampling locations. In households without pets, 3.0% of all dust samples contained cat, dog or other animal hairs. Of the dust samples from households without pets, pet hairs were collected from all locations; 57.1% were cat hairs and 28.6% were dog hairs.

As expected, significantly more pet hairs were found in the families with pets households (17.80, S.E. 6.59) compared with the three demographics without pets; families without pets (0.20, S.E. 0.16), students without pets (0.80, S.E. 0.41) and over 65 s without pets (0.60, S.E. 0.33), ($p < 0.001$) excluding the number of hairs from the child's mattress and toy. Within the families with pets households who had at least one pet cat or dog, there was a significant difference ($p = 0.004$) between the total number of cat and dog hairs found in different locations. The greatest number of cat and dog hairs were found in the living room carpet (13.53, S.E. 8.21), followed by the sofa (4.00, S.E. 2.46), car (3.25, S.E. 2.01), child's soft toy (1.25, S.E. 0.83), top surface (1.00, S.E. 0.69), child's mattress (0.88, S.E. 0.61) and master bedroom mattress (0.13, S.E. 2.04).

Survey

Participants' cleaning behaviour and perceptions of cleanliness were determined by asking participants to complete a survey. All 40 enrolled participants completed and returned the survey prior to dust collection. The mean number of residents differed in each demographic group ($p = 0.024$): families without pets had the highest number of residents (3.9, S.E. 0.62), followed by families with pets (3.7, S.E. 0.61), students without pets (3.1, S.E. 0.56) and over 65 s without pets

had the lowest number of residents in the household (1.8, S.E. 0.42). In the households of families with pets: three had a dog, three had one or two cats, two households had one dog and one cat, one had rabbits and one household had a budgie.

Importance of cleaning

On average, participant households were cleaned 1.69 ± 0.6 times per week (Incidence Rate $\pm$ S.E.). Perhaps surprisingly, no significant differences were seen between how often the different household types were cleaned ($p = 0.394$; families with pets 1.65 ± 0.6 ; families without pets 1.20 ± 0.6 ; students without pets 1.70 ± 0.6 ; over 65 s without pets 2.20 ± 0.6). In total, 62.5% of participants stated that cleaning is 'quite' important to them, 32.5% of participants reported that cleaning is 'very' important, and 6.0% of participants disclosing that cleaning is 'not' important to them.

Household area cleanliness. The cleanest area, and the most-cleaned area, was perceived to be the kitchen (53.8% and 66.3% respectively), followed by the bathroom (16.3% and 10.0% respectively) and living room (15.0% and 12.5% respectively).

The kitchen was reported as the cleanest area by the majority of participants (at least 60% of families and over 65 s), but 40% of student participants felt the bedroom was the cleanest area overall (40% bedroom, 30% kitchen). Only one participant from the families with pets demographic stated that they clean everything equally.

A variety of areas were stated as the least clean across the four demographic groups, but overall, participants thought the bedroom was the least clean area (28.8% of all participants) (Table 2). The bedroom was stated as the area cleaned the least for all demographics apart from students, who reported the bathroom (30% of participants) and hallway (30% of participants) as areas cleaned the least.

Cleaning tasks. The most disliked cleaning task was vacuuming, as reported by 22.5% of all participants (Figure 3). This was followed by dusting (21.3% of all participants) and cleaning the toilet (20% of all participants). From the families with pets group, the most disliked cleaning task was vacuuming (50% of participants) followed closely by dusting (40% of participants). Vacuuming was also the most disliked cleaning task by families without pets along with cleaning the toilet (30% of participants). The most disliked cleaning task for students was cleaning the floors, as reported by 40% of participants. Participants from the over 65 s households disliked dusting the most (30%), followed closely by cleaning the toilet and bathroom (20%). Cleaning the toilet and bathroom were the only cleaning tasks that participants from all four demographics mentioned they disliked.

Overall, the living room carpet was vacuumed the most frequently, with the majority of households vacuuming more frequently than monthly (92% of all households), 40% of households vacuuming every week and 27.5% vacuuming more than once per week (Figure 4). Eighty per cent of over 65 s without pets vacuumed the living room carpet weekly and 60% of families with pets vacuumed more than once a week. In contrast, 60% of all households never vacuumed their bedroom mattress, with 80% of families without pets and students without pets never vacuuming their mattress. The majority of families with pets (50%), students without pets (60%) and over 65 s without pets (50%) vacuumed the car monthly, whereas the half of families without pets (50%) never vacuumed the car. The majority of families with and without pets never vacuumed the child's mattress (80% of all family households) and the child's toy (95% of all family households).

Discussion

This study investigated the contents of 240 household dust samples with the aim of determining whether demographic (family, student and over 65 s), the presence of pets, or location in the car and home were related to dust content. The reported cleaning behaviours and perceptions of

Table 2. Areas of the participating households reported as the least clean and cleaned the least.

Area	Bathroom	Bedroom	Conservatory	Dining room	Everywhere	Hallways	Hard to reach places	Kitchen	Living room	Playroom	Stairs	Stairs: under	Store room	Study	Top Floor	Utility/ lobby
Least clean (% participants)																
FP	10	40	0	0	10 ^A	10	10	0	10 ^B	0	10	0	0	0	0	0
F	0	50	10	0	0	10	20	0	0	0	10	0	0	0	0	0
S	20	10	0	10	0	20	10	30	0	0	0	0	0	0	0	0
O	10	15	0	0	10 ^A	0	10	5	10	10	0	0	10	10	0	10
All	10	28.8	2.5	2.5	5 ^A	10	12.5	8.8	5	2.5	5	0	2.5	2.5	0	2.5
Cleaned the least (% participants)																
FP	10	50	0	0	0	10	10	0	10	0	0	10	0	0	0	0
F	0	60	10	0	0	10	10	0	10	0	0	0	0	0	0	0
S	30	20	0	0	0	30	0	10	0	0	0	0	0	0	10	0
O	0	40	10	0	0	0	0	0	20	10	0	0	10	10	0	0
All	10	45	5	0	0	10	5	2.5	10	2.5	0	2.5	2.5	2.5	2.5	0

FP = families with pets, F = families without pets, S = students without pets, O = over 65s without pets, ^A apart from the cleanest areas, ^B around the pet.

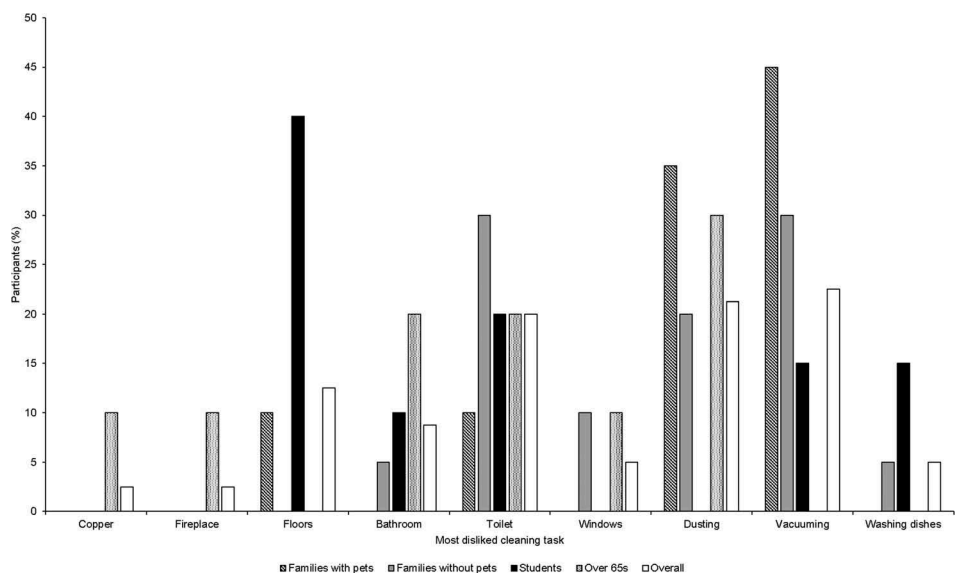


Figure 3. Cleaning tasks that participants disliked the most.

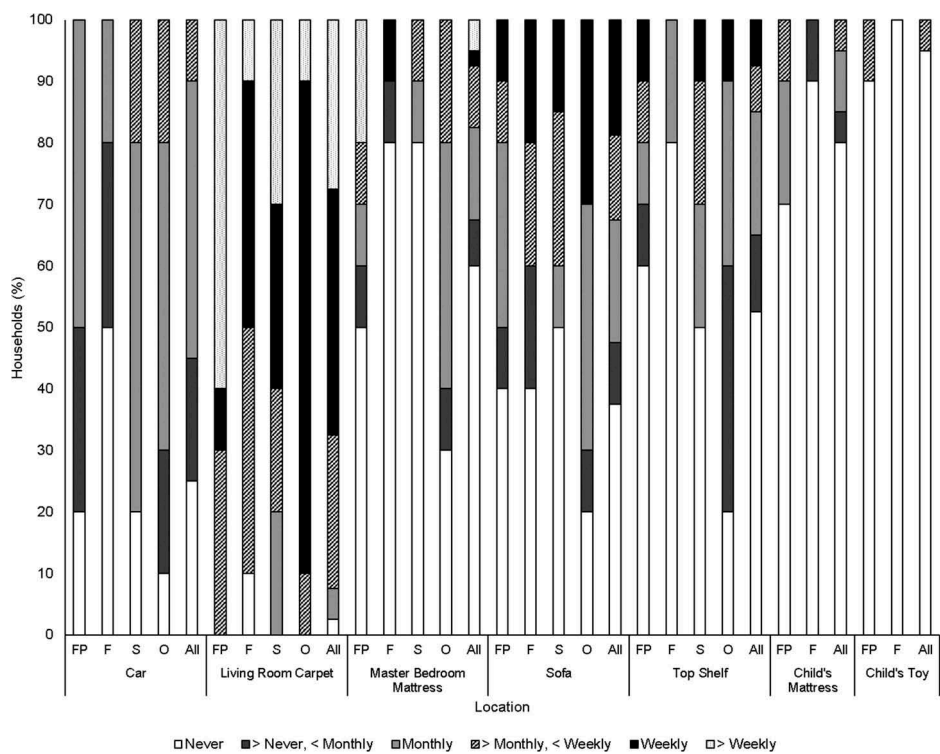


Figure 4. The frequency of vacuuming the seven sampling locations. FP = families with pets, F = families without pets, S = students without pets, O = over 65s without pets.

cleanliness across the demographic groups were also compared to investigate if they had an impact on the dust contents of participants' cars and homes.

House dust mites were found across all demographics and sampling locations, as was the *Der p 1* house dust mite allergen. This suggests that all of our sampling locations provided suitable environmental conditions and a food source to sustain naturally occurring populations of house dust mites, though not every sample contained house dust mites. Frequent vacuuming is known to help alleviate the symptoms of dust-related diseases (Wu et al. 2012), and while overall, differences between demographics were not significant, a larger percentage of samples from the family groups (those with pets and without) contained mites. Interestingly, these groups also reported that the cleaning task they liked least was vacuuming. Families without pets collected the most dust in their samples, both from their homes and their cars. Perhaps the presence of a pet in the family encourages more frequent cleaning – in fact, the survey data would support this.

The number of house dust mites collected in samples were fewer than anticipated; where a previous study found around 1–200 mites per gram of dust collect from mattresses (Cameron and Hill 2002), we were generally finding less than 20 mites per gram. A potential explanation for this may be the time of year this study was conducted, as we know mite densities fluctuate with seasons (Lintner and Brame 1993), though in the Cameron and Hill (Cameron and Hill 2002) study, the greatest mite numbers were detected in November, and therefore around the same time of year as this study was conducted. The majority of participants never vacuumed their master bedroom mattress, (which has also been noted in a previous study (Wu et al. 2012)) or their child's mattress; so it is unlikely that the low numbers are due to heavy vacuuming prior to enrolling in the study. Another explanation may be the template size or duration of vacuuming, which were set in order to standardize the collection method.

Often we associate the bedroom mattress to be the primary source of house dust mites in the house. Two studies conducted in homes in Sydney, Australia found the bedroom mattress to be the main source of *Der p 1* allergen, followed by the bedroom carpet, followed by the living room floor (Marks et al. 1995; Mahrshahi et al. 2002). In this study however, a higher number of dust mites per gram of dust were collected from the sofa than the other locations. In fact, we found the greatest titres of dust mite allergen in the living room carpet, not in the bedroom. Another study has found household *Der p 1* allergen exposure to be lowest at night time (Tovey et al. 2013), contrary to what one might expect should the bedroom mattress be the main source of mites. A study by Custovic et al. (1999) investigated the levels of *Der p 1* in reservoir dust (as in this study) and found a range of 0.2–66 µg/gr of *der p 1* from living room floors. Here, we detected a median of 254 ng/g (0.254 µg/g) of *Der p 1* allergen from living room carpets, so on the lower end of a similar range.

One must consider the small size of this study and cannot discount the fact that there are many variables that affect *Der p 1* levels, such as age of carpet and type of mattress (Wickens et al. 1997), which were not measured in this study. We were also not able to collect enough dust to perform the *Der p 1* analysis on all the samples collected from the child's toy. This may have been because the dust collection was not efficiently or consistently done – as the participants themselves collected the dust, or because the toys were not old enough/too clean. A study by Wu et al. (2014) found measurable amounts of *Der p 1* in all 40 soft toys included in dust sampling. They found on average three times the amount of *Der p 1* in the toy samples compared with those collected from mattresses, making children's toys an important source of allergen. This is significant for families with children who suffer from allergy.

Surveys showed that 50% of families without pets never vacuumed their car. Overall, a greater weight of dust was collected from cars belonging to families without pets compared with students and the over 65 s. The lowest percentage of samples containing skin cells (which house dust mites feed on) were also collected from the car, which may relate to the low concentration of *Der p 1* present in these samples, and may be due to people spending less time in their car, approximately 35 min a day (National Travel Survey 2010), compared with indoors. Alternatively, house dust

mites and *Der p 1* could have been transferred to cars, via clothing, hair and skin, therefore populations of dust mites in cars could have originated from indoor biotopes (Mason et al. 2015; Clarke et al. 2015a).

Human hair was another common constituent of dust and was found across all demographics and sampling locations. As humans shed approximately 100–150 hairs a day (Malkud 2015), it is unsurprising that human hairs were present in 71.7% of dust samples. Significantly fewer human hairs were collected from the over 65 s demographic. Reasons for this may be because there were fewer inhabitants in the over 65 s households, which has been noted as a determinant of dust content (Barberan et al. 2015). Hair follicle density on the scalp decreases with age which could also contribute to this finding (Sinclair et al. 2004; Paus and Peker 2008). Human hair may be an important reservoir for allergens including *Der p 1*, but also cat and dog-derived allergens (Karlsson and Renstrom 2005; Liccardi et al. 2005; Krop et al. 2007). Cat and dog hairs were found across all sampling locations in families with at least one cat or dog. In these households, cat and dogs hairs were mostly in communal areas of the home, including the living room carpet and sofa. A study conducted by Zahradnik and Raulf (Zahradnik Eva and Raulf Monika 2014) reported that the highest concentrations of cat and dog allergens were in the living room sofas, supporting our findings, and also that high concentrations suggested that the pet favoured that location in the home. There were significantly more pet hairs present in dust samples collected from families with pets when compared with the three demographics without pets, but interestingly, pet hairs were *also* identified in samples from households where no pets were present.

In general, participants reported their kitchen as the cleanest room in the house and spent more time cleaning the kitchen than other areas. Students on the other hand, tended to consider their bedrooms the cleanest part of the house. This was not obviously reflected in the amount of dust collected from the beds from different households, though samples were not taken from the bedroom carpet or kitchens. While not significant, the dust samples from Students' living room carpets were noticeably heavier. Unfortunately, it was not possible to make comparisons of the dust mite numbers and allergen titres between these groups by location in the home due to a limited number of samples. Overall, the median concentrations of house dust mite allergen were lower than the documented threshold value for risk of sensitization, 2000 ng g⁻¹ (Van Strien et al. 2003).

Interestingly, toe nails were found only in living room carpet and sofa samples, which were the two locations that also had the highest percentage of samples containing food matter. These findings may reflect day-to-day habits of residents, and may suggest that they are not fully aware of the contents of the environment around where they eat. A study conducted by Oxford et al (Oxford et al. 2013) found that participants cleaned their house to 'look clean, smell nice and remove germs'. The kitchen and bathroom are two locations in the home that carry particularly high levels of bacteria (Scott 2000; Kagan et al. 2002; Oxford et al. 2013). Therefore, it is no surprise that we found that the majority of participants reported the kitchen as the cleanest area and the area cleaned the most in the home. Although cleaning the bathroom and toilet were the only cleaning tasks that participants from all four demographics disliked. Six per cent of participants felt that cleaning was not important. In fact, trends show that homes are cleaned for superficial reasons, rather than focusing on the health and hygiene implications (Bloomfield et al. 2006). Therefore, it would be interesting to investigate further the rationale behind the responses to the importance and frequency of cleaning, to see if this has an impact on cleaning mentalities.

Overall, we demonstrated that the contents of dust varies across locations of the home, though no obvious differences in house dust mite numbers or allergen titres were noted between demographic groups. One noticeable difference between demographic groups was the type and quantity of hair collected in samples. Contrary to common opinion on where we are most exposed to allergens, this study found that while the living room carpet was vacuumed frequently, *Der p 1* allergen was measured in the greatest quantity in the living room. Our results contribute to the understanding of dust content in relation to cleaning behaviour and perceptions of cleanliness. Our method is easily

amenable to dust analysis by future researchers. As this was a pilot study, we recommend that the sample size should be increased in future studies to provide data more representative of the demographic groups, that the duration of sample collection and number of samples collected are increased to ensure sufficient quantities of dust are available for house dust mite quantification and to run ELISAs. The results of this study may improve understanding of attitudes to cleaning and perceptions of cleanliness. There are differences in the way different demographics clean their homes and this may have effects on house dust mites and allergens. As regular vacuuming and dusting is a recommended measure in controlling exposure to dust mite and pet allergens (Colloff et al. 1992; Durham 1996), household attitudes towards cleaning and perceptions of cleanliness should be a consideration for health advisors and manufacturers when designing their products. Furthermore, a greater understanding of where in the home you find the greatest levels of allergens may help individuals suffering from dust-related allergies to change their attitude or approach to cleaning their home.

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Notes on contributors

Lucy Casley was previously the Study Coordinator at ARCTEC. Her background and training was in forensic entomology. She is now the *BASIL-2* Trial Co-ordinator within the Birmingham Clinical Trials Unit (BCTU).

Tom Godec is a Research Fellow in the Department of Medical Statistics, Faculty of Epidemiology and Population Health at the London School of Hygiene and Tropical Medicine.

James G. Logan is the Head of the Department of Disease Control and Director of the Arthropod Control Product Test Centre (ARCTEC). He is Principal Investigator of a large research portfolio investigating novel ways to control arthropod vectors that transmit pathogens of medical importance, including Zika, malaria and dengue. James is the United Kingdom's leading expert on insect repellents and methods of personal protection against arthropod vectors. Through chemical ecology studies, his research group explores the complex interaction between arthropod vectors, vertebrate hosts and pathogens at the behavioural, olfactory and molecular level. The Logan group also investigates the mode of action of new (and current) monitoring and control technologies for arthropods, using in-house state-of-the-art experimental equipment including electroantennography, single sensillum recording, gas chromatography, RT-PCR and behavioural olfactometry as well as Category 3 facilities which allow complex malaria infection studies with *Anopheles gambiae* mosquitoes and *Plasmodium falciparum* parasites. The ARCTEC laboratories, and well-stocked insectaries, house excellent facilities for the development and high-throughput evaluation of arthropod-related products and technologies for pest and vector control. James and his team are Good Clinical Practice-trained and highly practiced in coordinating clinical trials on commercial products including repellents, after-bite treatments and head lice treatments. James began his career with a first class BSc honours degree in Zoology from the University of Aberdeen in 2001 and an award-winning PhD in 2005. He then led a research group at Rothamsted Research, as Senior Postdoctoral Research Scientist, within the Chemical Ecology Programme, before joining the School.

James C. Pearce is a Research Assistant at ARCTEC, which involves the day-to-day management of the insectaries and conducting both clinical and non-clinical trials in our various testing facilities. He graduated from the University of Bristol in 2011 with a degree in Biological Sciences.

Hugh was previously a Research Assistant at ARCTEC. He joined ARCTEC in 2015 after being employed by Rentokil as a pest control technician. He is currently employed by Royal Parks.

Sophie is a Senior Scientist and Clinical Projects Manager for ARCTEC. She joined in 2012 and as a member of Senior Management, she is responsible for implementing quality systems in project oversight and ensuring that as a team, we work effectively together to achieve excellent research.

She has over 11 years of experience in entomology, with a PhD from Imperial College London in plant-insect interactions.

Sarah has over 17 years' experience in entomological and chemical ecology research. After completing a Bachelors degree (2:1) at Birmingham University in Biological Sciences and an MSc at the University of Bath, I obtained a PhD at Imperial College, London in chemical ecology whilst working at Rothamsted Research. She has worked at ARCTEC since 2014, where she is employed as a Senior Research Scientist and Projects Manager.

ORCID

Sophie A. Stewart  <http://orcid.org/0000-0001-5673-0860>

References

- Amaro R, Coelho SD, Pastorinho MR, Taborda-Barata L, Vaz-Patto MA, Monteiro M, Nepomuceno MCS, Lanzinha JCG, Teixeira JP, Pereira CC, et al. 2016. House dust fungal communities' characterization: a double take on the six by sixty by six (6 x 60x 6) project. *Open Eng.* 6(1):542–547.
- Arbes SJ Jr., Cohn RD, Yin M, Muilenberg ML, Burge HA, Friedman W, Zeldin DC. 2003. House dust mite allergen in US beds: results from the first national survey of lead and allergens in housing. *J Allergy Clin Immunol.* 111(2):408–414.
- Arlian LG, Morgan MS. 2003. Biology, ecology, and prevalence of dust mites. *Immunol Allergy Clin North Am.* 23(3):443–468.
- Arlian LG, Platts-Mills TA. 2001. The biology of dust mites and the remediation of mite allergens in allergic disease. *J Allergy Clin Immunol.* 107(3 Suppl):S406–413.
- Bailey D. 2016. *Practical Veterinary Forensics*. Wallingford (UK): CABI.
- Barberan A, Dunn RR, Reich BJ, Pacifici K, Laber EB, Menninger HL, Morton JM, Henley JB, Leff JW, Miller SL, et al. 2015. The ecology of microscopic life in household dust. *Proc Biol Sci.* 282:1814.
- Binotti RS, Oliveira CH, Santos JC, Binotti CS, Muniz JRO, Prado AP. 2005. Survey of acarine fauna in dust samplings of curtains in the city of Campinas, Brazil. *Braz J Biol.* 65:25–28.
- Bloomfield SF, Stanwell-Smith R, Crevel RW, Pickup J. 2006. Too clean, or not too clean: the hygiene hypothesis and home hygiene. *Clin Exp Allergy.* 36(4):402–425.
- Cameron MM, Hill N. 2002. Permethrin-impregnated mattress liners: a novel and effective intervention against house dust mites (Acari: pyroglyphidae). *J Med Entomol.* 39(5):755–762.
- Clarke D, Burke D, Gormally M, Byrne M. 2015a. Dynamics of house dust mite transfer in modern clothing fabrics. *Annals of Allergy, Asthma & Immunology: Official Publication of the American College of Allergy, Asthma, & Immunology.* 114(4):335–340.
- Clarke D, Gormally M, Sheahan J, Byrne M. 2015b. Child car seats - a habitat for house dust mites and reservoir for harmful allergens. *Annals of Agricultural and Environmental Medicine: AAEM.* 22(1):17–22.
- Colloff MJ, Ayres J, Carswell F, Howarth PH, Merrett TG, Mitchell EB, Walshaw MJ, Warner JO, Warner JA, Woodcock AA. 1992. The control of allergens of dust mites and domestic pets: a position paper. *Clin Exp Allergy.* 22(Suppl 2):1–28.
- Custovic A, Simpson B, Simpson A, Hallam C, Craven M, Woodcock A. 1999. Relationship between mite, cat, and dog allergens in reservoir dust and ambient air. *Allergy.* 54(6):612–616.
- Durham SR. 1996. Allergen avoidance measures. *British Thoracic Society. Respir Med.* 90(8):441–445.
- Erwin EA, Wickens K, Custis NJ, Siebers R, Woodfolk J, Barry D, Crane J, Platts-Mills TA. 2005. Cat and dust mite sensitivity and tolerance in relation to wheezing among children raised with high exposure to both allergens. *J Allergy Clin Immunol.* 115(1):74–79.
- Garrett MH, Hooper BM, Hooper MA. 1998. Indoor environmental factors associated with house-dust-mite allergen (Der p 1) levels in south-eastern Australian houses. *Allergy.* 53(11):1060–1065.
- Jacquet A. 2013. Innate immune responses in house dust mite allergy. *ISRN Allergy.* 2013:1–18.
- Jr RR O, Fox MJ. 1998. *Atlas of human hair: microscopic characteristics*. LLC, Florida (US): CRC Press.
- Kagan LJ, Aiello AE, Larson E. 2002. The role of the home environment in the transmission of infectious diseases. *J Community Health.* 27(4):247–267.
- Karlsson AS, Renstrom A. 2005. Human hair is a potential source of cat allergen contamination of ambient air. *Allergy.* 60(7):961–964.
- Krop EJ, Doekes G, Stone MJ, Aalberse RC, Van Der Zee JS. 2007. Spreading of occupational allergens: laboratory animal allergens on hair-covering caps and in mattress dust of laboratory animal workers. *Occup Environ Med.* 64(4):267–272.
- Liccardi G, Barber D, Russo M, D'Amato M, D'Amato G. 2005. Human hair: an unexpected source of cat allergen exposure. *Int Arch Allergy Immunol.* 137(2):141–144.
- Linacre A. 2009. *Forensic science in wildlife investigations*. Florida (US): CRC press, Taylor & Francis Group.
- Lintner TJ, Brame KA. 1993. The effects of season, climate, and air-conditioning on the prevalence of dermatophagoides mite allergens in household dust. *J Allergy Clin Immunol.* 91(4):862–867.
- Malkud S. 2015. Telogen effluvium: a review. *J Clin Diagn Res.* 9(9):WE01–03.
- Marks GB, Tovey ER, Toelle BG, Wachinger S, Peat JK, Woolcock AJ. 1995. Mite allergen (Der p 1) concentration in houses and its relation to the presence and severity of asthma in a population of Sydney schoolchildren. *J Allergy Clin Immunol.* 96(4):441–448.

- Mason HJ, Smith I, Anua SM, Tagiyeva N, Semple S, Devereux G. 2015. Levels of house dust mite allergen in cars. *Arh Hig Rada Toksikol.* 66(3):209–212.
- Mihirshahi S, Marks G, Vanlaar C, Tovey E, Peat J. 2002. Predictors of high house dust mite allergen concentrations in residential homes in Sydney. *Allergy.* 57(2):137–142.
- Moore JE. 1988. A key for the identification of animal hairs. *J Forensic Sci Soc.* 28(5–6):335–339.
- Oxford J, Berezin EN, Courvalin P, Dwyer D, Exner M, Jana LA, Kaku M, Lee C, Letlape K, Low DE, et al. 2013. An international survey of bacterial contamination and householders' knowledge, attitudes and perceptions of hygiene. *J Infect Prev.* 14(4):132–138.
- Paus R, Peker S. 2008. Chapter 68, Biology of hair and nails. In: *Jl B, Jorizzo JL, Rapin RP, editors. Dermatology. Spain: Elsevier Limited.*
- Platts-Mills TA. 2007. The role of indoor allergens in chronic allergic disease. *J Allergy Clin Immunol.* 119(2):297–302.
- Platts-Mills TA, Vervloet D, Thomas WR, Aalberse RC, Chapman MD. 1997. Indoor allergens and asthma: report of the third international workshop. *J Allergy Clin Immunol.* 100(6 Pt 1):S2–24.
- Portnoy J, Miller JD, Williams PB, Chew GL, Miller JD, Zaitoun F, Phipatanakul W, Kennedy K, Barnes C, Grimes C, et al. 2013. Environmental assessment and exposure control of dust mites: a practice parameter. *Annals of Allergy, Asthma & Immunology: Official Publication of the American College of Allergy, Asthma, & Immunology.* 111(6):465–507.
- Sanchez-Borges M, Fernandez-Caldas E, Thomas WR, Chapman MD, Lee BW, Caraballo L, Acevedo N, Chew FT, Ansotegui IJ, Behrooz L, et al. 2017. International consensus (ICON) on: clinical consequences of mite hypersensitivity, a global problem [journal article]. *World Allergy Organ J.* 10(1):14.
- Scott E. 2000. Relationship between cross-contamination and the transmission of foodborne pathogens in the home. *Pediatr Infect Dis J.* 19(10 Suppl):S111–113. eng.
- Siebers RW, Rains N, Fitzharris P, Crane J. 1998. House dust mite allergen (Der p 1) in human hair. *J Allergy Clin Immunol.* 101(3):421–422.
- Sinclair R, Chapman A, Magee J. 2004. The lack of significant changes in scalp hair follicle density with advancing age. *Br J Dermatol.* 152:646–649.
- Sun JL, Shen L, Chen J, Yu JM, Yin J. 2014. Mite and booklouse fauna from vacuumed dust samples from Beijing. *Allergy Asthma Immunol Res.* 6(3):257–262.
- Survey NT. 2010. Department of Transport. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/8932/nts2010-01.pdf [Accessed 19/01/2018].
- Tovey ER, Willenborg CM, Crisafulli DA, Rimmer J, Marks GB. 2013. Most personal exposure to house dust mite aeroallergen occurs during the day. *PLoS One.* 8(7):e69900.
- Van Strien RT, Koopman LP, Kerkhof M, Oldenwening M, De Jongste JC, Gerritsen J, Neijens HJ, Aalberse RC, Smit HA, Brunekreef B, et al. 2003. Mattress encasings and mite allergen levels in the Prevention and Incidence of Asthma and Mite Allergy study. *Clin Exp Allergy.* 33(4):490–495.
- Warner J, Little S, Pollock I, Longbottom J, Warner J. 1990. The influence of exposure to house dust mite, cat, pollen and fungal allergens in the home on primary sensitisation in asthma. *Pediatr Allergy Immunol.* 1(2):79–86.
- Wickens K, Siebers R, Ellis I, Lewis S, Sawyer G, Tohill S, Stone L, Kent R, Kennedy J, Slater T, et al. 1997. Determinants of house dust mite allergen in homes in Wellington, New Zealand. *Clin Exp Allergy.* 27(9):1077–1085.
- Wu FFS, Wu MW, Pierse N, Crane J, Siebers R. 2012. Daily vacuuming of mattresses significantly reduces house dust mite allergens, bacterial endotoxin, and fungal beta-glucan. *J Asthma.* 49(2):139–143.
- Wu FFS, Wu MW, Ting MH, Crane J, Siebers R. 2014. Cat, dog and house dust mite allergen levels on children's soft toys. *J Asthma.* 51(1):75–78.
- Zahradnik E, Raulf M. 2014. Animal allergens and their presence in the environment [review]. *Front Immunol.* 5(76):76.
- Zock JP, Heinrich J, Jarvis D, Verlato G, Norback D, Plana E, Sunyer J, Chinn S, Olivieri M, Soon A, et al. 2006. Distribution and determinants of house dust mite allergens in Europe: the European Community Respiratory Health Survey II. *J Allergy Clin Immunol.* 118(3):682–690.