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Dynamics of house dust mite transfer in modern clothing fabrics

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ABSTRACT

Background: Clothing is largely presumed as being the mechanism by which house dust mites are distributed among locations in homes, yet little research to date has investigated the capacity with which various clothing fabric types serve as vectors for their accumulation and dispersal. Although previous research has indicated that car seats provide a habitat for mite populations, dynamics involved in the transfer of mites to clothing via car seat material is still unknown.

Objective: To investigate the dynamics involved in the transfer of house dust mites from car seat material to modern clothing fabrics.

Methods: A total of 480 samples of car seat material were seeded with mites and subjected to contact with plain woven cotton, denim, and fleece. Contact forces equivalent to the mass of a typical adult and child were administered for different durations of contact.

Results: Mean transfer efficiencies of mites from car seat material to receiving clothing fabrics ranged from 7.2% to 19.1%. Fabric type, mite condition (live or dead), and the force applied all revealed a significant effect ($P < .001$ for each variable) on the transfer efficiency of house dust mites from seeded material to receiving fabrics, whereas duration of contact revealed no effect ($P = .20$). In particular, mean numbers of mites transferred to fleece (compared with denim and plain woven cotton) were greater for each treatment.

Conclusion: These findings indicate that clothing type can have important implications for the colonization of other biotopes by house dust mites, with potential for affecting an individuals' personal exposure to dust mite allergens.

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Introduction

Allergic sensitization to house dust mites is a worldwide problem.^{1–3} Mattresses, carpets, and upholstery serve as the primary habitats for house dust mites—areas where their main dietary component (ie, human skin scales) accumulate easily. To date, a wealth of research examining the presence and density of house dust mites in such habitats has been conducted.^{4–7} Presence and quantities of house dust mites have also been reported for private vehicles,^{8–10} whereas public transport vehicles, such as buses,¹¹ trains,¹² airplanes,¹³ and taxis,¹⁴ have all been identified as important sources of house dust mite allergen exposure.

House dust mites are also present in clothing, which has been identified as the most likely mechanism by which mites colonize other locations and are dispersed throughout the home.^{15,16} The potential of clothing to harbor large populations of house dust mites has been previously reported,¹⁷ with more than 30,000 live

specimens recovered from a single-knitted jacket using the heat escape sampling method. In Australia, a mean density of 8.6 live mites per 100 cm² was recovered from 8 of 15 clothing items also using the heat escape sampling method, whereas a mean quantity of 15.9 µg/g of Der 1 allergen was reported from 35 clothing items.¹⁸ A study in Israel¹⁹ reported mites from all samples taken from clothing and bedding of 19 children with atopic dermatitis, listing a range of species present.

Increased personal house dust mite allergen exposure through clothing has been observed previously,²⁰ with woolen garments found to contain higher levels of Der p 1 than other fabrics.^{20,21} In contrast, a US study recovered low densities of house dust mites and Der 1 allergen content from clothing,⁹ but noted that 70% of the individuals whose clothing samples contained mites also had mites in their automobiles and homes. Trials using stained house dust mites to examine their dispersal in a home revealed that specimens released on a couch appeared on children's clothing via contact with the couch after 3 hours, while also dispersing to the family vehicle within 24 hours.¹⁶

A recent investigation found that more than 80% of child car seats sampled in a survey contained mites,¹⁰ whereas more than 15% contained mite densities above the lower threshold level of 100

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mites per gram of dust,²² highlighting the importance of a previously neglected focus for house dust mite populations. Although it is likely that these populations were originally established from indoor biotopes via clothing, it is also possible that the reverse is true (ie, that car seats serve as important biotopes for contaminating clothing with house dust mites). Contact between clothing and car seats, either in an instantaneous capacity or over longer time periods, may have the propensity to transport mites among biotopes within the home or elsewhere and contribute to an individual's personal allergen exposure. Recent research has suggested that the traditional view of greater house dust mite allergen exposure at night when resting in bed may need to be reviewed because greater levels of personal allergen exposure were detected in association with domestic activity and proximity to other people during the day rather than in bed.²³ Personal allergen exposure is also likely to be influenced by the type of clothing worn by individuals because everyday clothing materials often vary considerably with regard to fabric type. In addition, it is not known whether properties of specific clothing fabrics, including weave pattern and pile structure, affect the capacity of a fabric to transfer house dust mites.

Although particle-borne contamination by surface-to-surface contact between soft and hard surfaces has been investigated previously,²⁴ the capacity with which different fabric types serve as vectors in the dispersal of mites has, to the best of our knowledge, not yet been examined. This provided the incentive for this study whereby, for the first time, the transfer of house dust mites (live and dead) from car seat material to different clothing fabrics was determined. The implications of the results for sensitized individuals are discussed.

Methods

Car seat material (100% polyester) was seeded with a known quantity of house dust mites and subjected to contact with 3 uncontaminated or clean fabric types. Experiments were performed under controlled laboratory conditions. The combined effects of fabric type, the contact force applied, and the duration of contact were observed to determine the effects of these variables on the transfer efficiencies of house dust mites between a typical car seat environment and modern clothing fabrics.

For each experimental treatment, car seat cover material (Fig 1A) made of 100% polyester (15 × 15 cm) was marked with a grid of 36 (4 cm²) squares. A single house dust mite specimen (*Dermatophagoides pteronyssinus*) was placed at the center of each square using a fine dissection needle. Each contaminated piece of car seat material was subjected to contact with a receiving uncontaminated fabric, examined before contact to ensure the absence of mites. Receiving fabrics consisted of the following 3 materials, which are constituents of modern day clothing and also vary quite considerably with regard to their microtopography:

- Plain woven cotton (Fig 1B): High-quality Egyptian cotton (thread count of 400) with a smooth surface topography.
- Denim (Fig 1C): A twill weave with thicker threads, more durable than plain weave and consisting of a more undulating surface topography
- Fleece (Fig 1D): A dense, synthetic fibrous material with a deep pile length of 3 to 4 mm.

Each of the 3 receiving fabrics was subjected to contact with the contaminated car seat material under 2 different forces and for 2 different periods. The forces applied were chosen to replicate: (1) the approximate force exerted by a child (aged 3 years) sitting in a child car seat (ie, 50 N) and (2) the approximate force exerted by an adult sitting in a car seat (ie, 75 N).

These values were deduced from mean age-weight percentile charts²⁵ with the values modified to account for the ratio of standing-to-sitting masses for both adults and children. These ratios were established in the current study from convenience sampling of both adults and children. Each applied force scenario was performed for 2 different durations of contact: (1) an instant contact period of approximately 3 seconds and (2) a sustained contact period of 20 minutes.

The instant contact period was chosen to replicate the act of a person sitting in a seat and quickly getting up again, whereas the sustained contact period was chosen with reference to the mean daily commuting time of citizens in Europe.²⁶ Experiments were undertaken separately with dead mites and live mites because both are encountered in a natural setting.^{9,10,27} For treatments using live mites, the perimeter of the experimental area was painted with a barrier fluid known as Insect-a-slip (BioQuip Products Inc, Compton, California), which, on the basis of preliminary trials, prevented the mites from escaping the experimental area. Fabrics were attached to a polystyrene foam sheet that was attached on its lower surface to a metal plate (Fig 2), the function of the foam being to replicate a typical car seat as closely as possible, while also allowing for compression of the plates to achieve the desired contact forces. When aligned correctly, the fabrics were then subjected to contact with each other using an axial torsion tester (Instron 8874, Fig 2) with which the desired force and duration of contact could be programmed for each treatment in the experiment. Mites were subsequently counted on the receiving fabric and the original contaminated fabric to ensure account was taken of all seeded mites. Experiments were conducted under laboratory conditions, with the recorded ambient temperature ranging from 26.2°C to 29.6°C and a relative humidity ranging from 49.2% to 56%. Each experiment was undertaken in exactly the same manner for each combination of fabric type, applied force, and duration of contact ensuring the validity of the experimental approach. In addition, each experiment was repeated 20 times, resulting in a total of 480 observations.

Results

Descriptive Analysis

Mean transfer efficiencies for various treatments (Table 1) ranged from 7.2 % (live mites transferred to denim under a force of 50 N for 3 seconds) to 19.1% (dead mites transferred to fleece under a force of 75 N for 20 minutes). With the exception of 3 treatments using plain woven cotton, the mean number of dead mites transferred to fabrics in each treatment was greater than those for live mites (Table 1). For both dead and live mites, mean numbers of mites transferred to fleece were greater than those transferred to plain woven cotton and denim (Fig 3). The mean number of mites transferred under an applied force of 75 N was greater than the mean number transferred under 50 N for both dead and live mites (Fig 4). Finally, mean dead mites transferred after 20 minutes of contact were greater than for 3 seconds, but for live mites slightly greater mean numbers were transferred after 3 seconds than after 20 minutes (Fig 5).

Inferential Analysis

Data were analyzed using Minitab 16 statistical software (Minitab Inc, State College, Pennsylvania). General linear model (GLM) analyses were used (Poisson regression could also have been used) to postulate a model for the number of mites transferred as a function of a number of input variables. Because the validity of this model requires homogeneity of variances of the responses at the different treatments. The response variable "number of mites transferred" was first transformed to "the square root of the

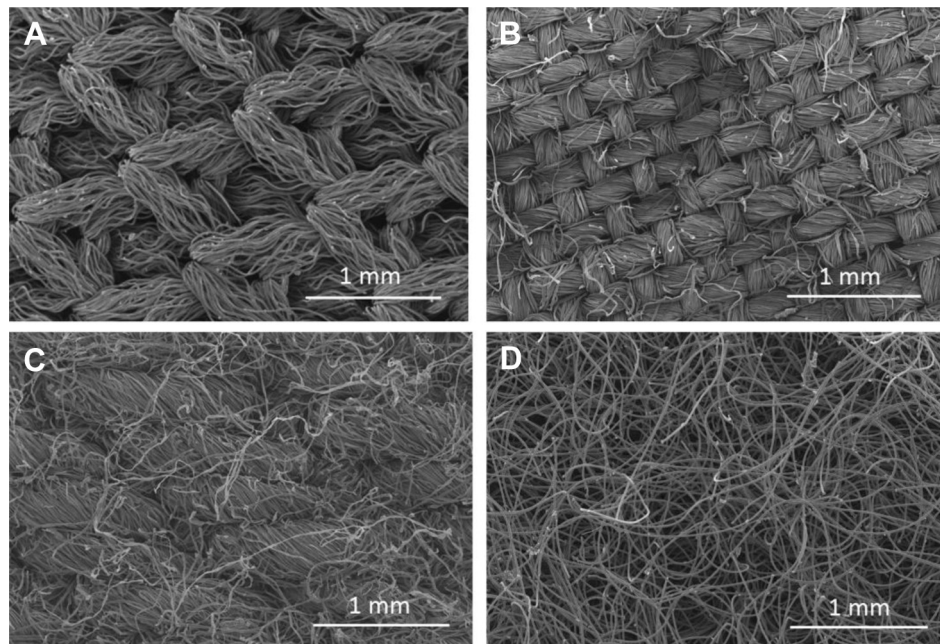


Figure 1. Scanning electron micrographs of the various fabric types used in the experiment: car seat cover material (100% polyester) (A), plain woven cotton (100% Egyptian cotton) (B), denim (100% cotton) (C), and fleece (100% polyester) (D).

number of mites transferred” then modeled using the following input variables: mite condition (ie, dead and live), fabric type (ie, plain woven cotton, denim, and fleece), force applied (50 N or 75 N), and duration of contact (3 seconds and 20 minutes). This model examined the effect of every possible combination of factors on the response variable (ie, the square root of the number of mites transferred) to determine which of the factors tested had a significant overall effect on the response variable. In addition, this model

was used to test for the presence of any interactions among the factors used.

The resulting main effects output from the GLM analysis is given in [Table 2](#). The mite condition, fabric type, and force applied input variables all had significant effects on the response variable. There was, however, no observed effect of duration of contact on the response variable. Further post hoc analyses (Tukey pairwise comparisons) were conducted on the 3 levels of the factor fabric

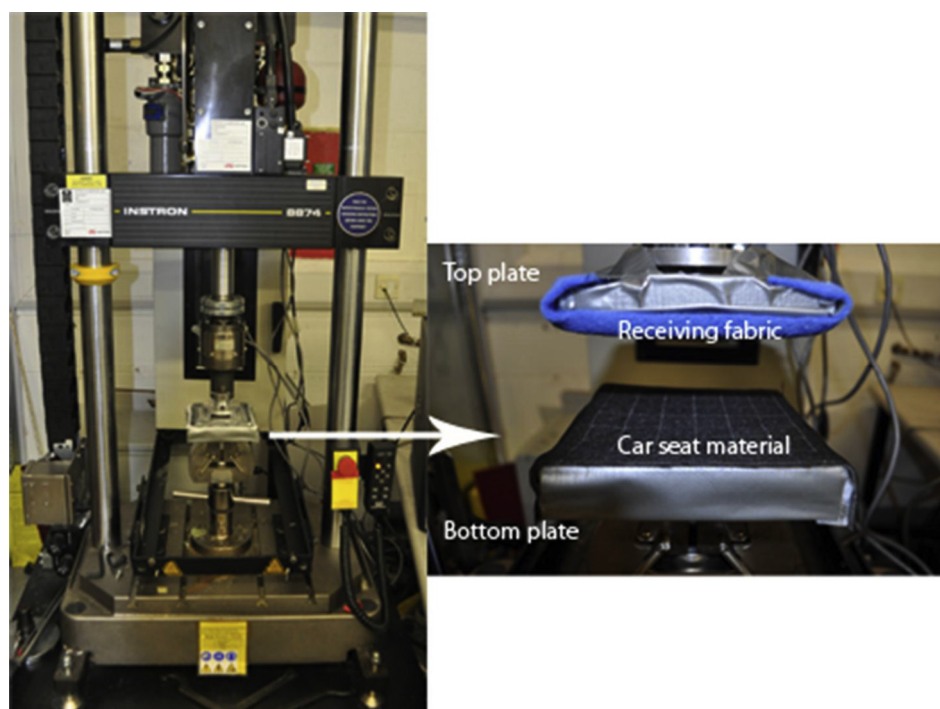


Figure 2. Axial torsion tester (Instron 8874) consisting of 2 contact plates with the contaminated car seat material (bottom plate) and the receiving fabrics plain woven cotton, denim, and fleece (top plate) attached.

Table 1

Mean $\pm$ SD (percentage transfer efficiencies) of dead and live house dust mites transferred to each fabric type under each treatment parameter tested

Condition and treatment	Plain woven cotton	Denim	Fleece
Dead			
F1, T1	3.0 $\pm$ 1.2 (8.3)	3.4 $\pm$ 1.0 (9.4)	6.4 $\pm$ 1.7 (17.8)
F1, T2	3.3 $\pm$ 1.6 (9.2)	3.9 $\pm$ 1.3 (10.8)	6.3 $\pm$ 1.8 (17.5)
F2, T1	3.4 $\pm$ 1.0 (9.4)	4.2 $\pm$ 1.6 (11.7)	6.1 $\pm$ 1.9 (16.9)
F2, T2	4.1 $\pm$ 1.3 (11.4)	5.2 $\pm$ 1.5 (14.4)	6.9 $\pm$ 2.0 (19.1)
Total	3.4 $\pm$ 1.3 (9.4)	4.2 $\pm$ 1.5 (11.7)	6.4 $\pm$ 1.8 (17.8)
Live			
F1, T1	3.0 $\pm$ 1.4 (8.3)	2.6 $\pm$ 1.1 (7.2)	4.3 $\pm$ 1.5 (11.9)
F1, T2	3.4 $\pm$ 1.3 (9.4)	2.8 $\pm$ 1.3 (7.8)	4.2 $\pm$ 1.4 (11.7)
F2, T1	3.6 $\pm$ 1.6 (10.0)	3.1 $\pm$ 1.6 (8.6)	5.6 $\pm$ 1.8 (15.6)
F2, T2	3.2 $\pm$ 1.4 (8.9)	3.1 $\pm$ 1.5 (8.6)	4.9 $\pm$ 2.0 (13.6)
Total	3.3 $\pm$ 1.3 (9.2)	2.9 $\pm$ 1.4 (8.1)	4.7 $\pm$ 1.7 (13.1)

Abbreviations: F1, force applied of 50 N; F2, force applied of 75 N; T1, duration of contact of 3 seconds; T2, duration of contact of 20 minutes.

type, which indicated a significant difference between the overall mean number of mites transferred to plain woven cotton and to fleece and between the mean number of mites transferred to denim and to fleece (Table 2).

The GLM also concluded that there was an interaction between the factors mite condition and fabric type. The presence of interactions among factors in this type of a model should be noted because the change in the expected number of mites transferred when moving from one level of a factor to another may depend on the level of another factor in the analysis. Hence, presence of an interaction among factors can potentially lead to an incorrect conclusion in the main effects output. In this case, the rate of change between the number of dead mites and the number of live mites transferred to plain-woven cotton was significantly different from that of denim, indicating that a significant interaction was present. However, on examining the main effects plots, the veracity of the relevant *P* values of the main effects in Table 2 could be confirmed, indicating that presence of this interaction did not have an overall influence on the factors involved.

Discussion

This study reveals that the quantity of house dust mites transferred from car seat material to clothing is determined by a number of variables. Among the 3 receiving fabrics used, fleece exhibited the highest mean transfer efficiency with both dead mites (17.8%)

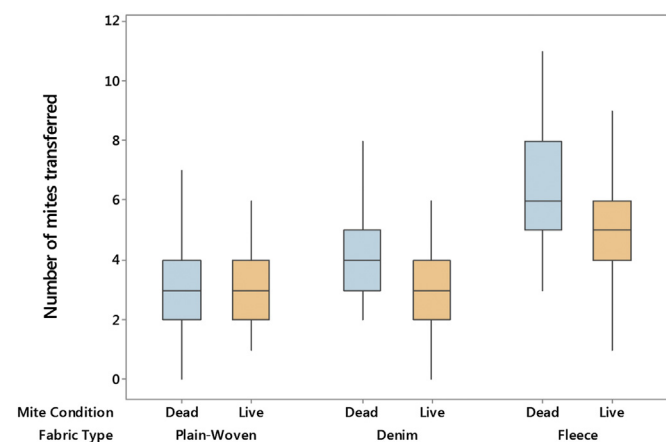


Figure 3. Dead and live mites transferred to each fabric type. Dead mites: plain woven cotton (mean $\pm$ SD, 3.4 $\pm$ 1.3), denim (mean $\pm$ SD, 4.2 $\pm$ 1.5), and fleece (mean $\pm$ SD, 6.4 $\pm$ 1.8). Live mites: plain woven cotton (mean $\pm$ SD, 3.3 $\pm$ 1.3), denim (mean $\pm$ SD, 2.9 $\pm$ 1.4), and fleece (mean $\pm$ SD, 4.7 $\pm$ 1.7).

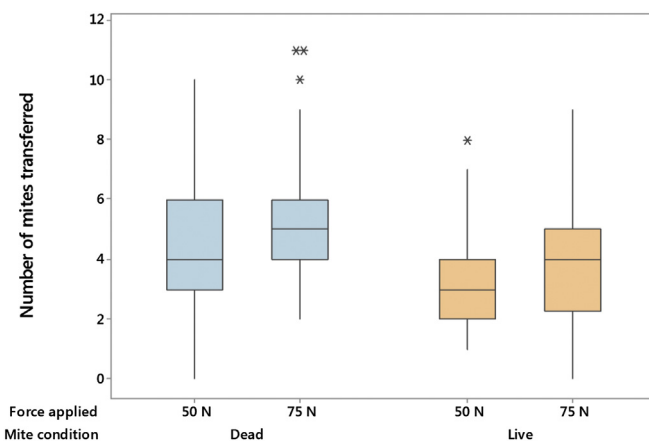


Figure 4. Dead and live mites transferred to receiving fabrics according to each force applied. Dead mites: 50 N (mean $\pm$ SD, 4.4 $\pm$ 2.0) and 75 N (mean $\pm$ SD, 5.0 $\pm$ 2.0). Live mites: 50 N (mean $\pm$ SD, 3.4 $\pm$ 1.5) and 75 N (mean $\pm$ SD, 3.9 $\pm$ 1.8). *Outlier in the data (ie, an observation that is outside the upper 25% of the distribution). **Two outliers with identical values.

and live mites (13.1%) compared with 11.7% and 8.1%, respectively, for denim and 9.4% and 9.2%, respectively, for plain woven cotton (Table 1). The differences in mean transfer efficiencies among fabrics are most likely explained by the contrasting microtopographies of each fabric. Fleece consists of a relatively complex network of polyester fibers (Fig 1D), providing a greater capacity to pick up and transfer house dust mites when placed in contact with an area of contaminated car seat material. A similar phenomenon has been observed previously,²⁴ with fleece reported as having a greater capacity to accumulate particulate contaminants than other materials such as cotton and plastic laminate, most likely because of the higher fiber pile present. Denim, a hard-wearing fabric, consists of a twill weave pattern of diagonal parallel ribs of cotton threads, resulting in an undulating, exposed topography. When viewed through a scanning electron microscope (Fig 1C), it is evident that many individual strands of cotton within the denim appear to become undone, creating an almost fuzzy appearance. Similar to fleece, the presence of these loose fibers may enhance the ability of bodies of house dust mites to adhere to denim, although evidently not to the same degree as fleece. In contrast, plain woven cotton presents a very tight weave that consists of very few loose strands (Fig 1B), resulting in a smooth, even topography, which is

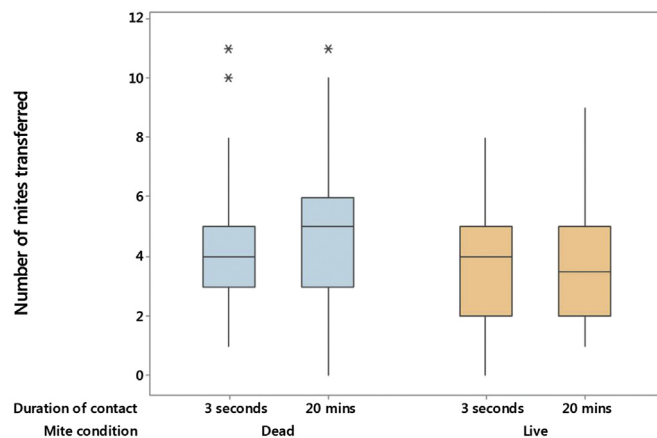


Figure 5. Dead and live mites transferred to receiving fabrics according to duration of contact. Dead mites: 3 seconds (mean $\pm$ SD, 4.4 $\pm$ 2.0) and 20 minutes (mean $\pm$ SD, 4.9 $\pm$ 2.1). Live mites: 3 seconds (mean $\pm$ SD, 3.7 $\pm$ 1.7) and 20 minutes (mean $\pm$ SD, 3.6 $\pm$ 1.6). *Outlier in the data (ie, an observation that is outside the upper 25% of the distribution).

Table 2

Portion of the general linear model output showing the *P* values associated with each main effect and the 95% confidence intervals (CI) for pairwise comparisons (difference in population means) of the levels of each factor

Variables	Factor levels	<i>P</i> value ^a	95% CI
Mite condition			
Dead–live	2	.000	0.26 ± 0.07
Fabric type	3	.000	
Pairwise comparisons for fabric			
Plain woven cotton—denim		.708	0.03 ± 0.10 ^b
Plain woven cotton—fleece		.000	0.53 ± 0.10 ^b
Denim—fleece		.000	0.50 ± 0.10 ^b
75N–50N	2	.000	0.14 ± 0.07
Time of contact			
20 minutes–3 seconds	2	.197	0.05 ± 0.07

^aSignificant *P* values are given in bold.

^b95% simultaneously CI.

likely to be the reason why fewer mites were transferred to this fabric.

With the exception of plain woven cotton, a greater mean number of dead mites were transferred than live mites for each treatment investigated. This may be attributed to instinctive capabilities that living mites possess to survive in their environment. *D pteronyssinus* has suckerlike appendages called pulvilli at the ends of its legs (Fig. 6), possibly helping it avoid transference by gaining a strong foothold on the substrate.²⁸ Because dead mites would not possess this ability, the lack of resistance to transfer may explain this result. It was observed on a number of occasions that after seeding with live mites, individual mites would move around on the fabric surface until finding a depression in the fabric, sometimes even managing to burrow underneath an individual thread. Because this did not happen with dead mites, it may also help explain why mean transfer efficiencies were higher with dead than with live mites.

As reported in the GLM output, a significant difference was found between the number of mites transferred between an applied force of 50 N and 75 N, with greater mean abundances transferred at the latter factor level. This finding suggests that small changes in force can affect the transfer of house dust mites between car seats and clothing materials. Similar observations regarding the effect of applied forces on transfer of deposited aerosol particles have been reported previously, with variance in quantities transferred depending on the type of contact fabric or material involved.²⁴ The inferential analysis in this study concludes that there was no overall effect of the duration of contact on the number of mites transferred from car seat material to the receiving fabrics. This result is similar

to other studies that examined the transfer of the bacterium *Salmonella typhimurium* from tiles, wood, and carpet to food²⁹ and the transfer of particulate matter among different surfaces,²⁴ both of which reported contact times to have no effect on the transfer efficiencies of their respective experimental subjects.

Although the aim of this study was to replicate, as closely as possible, a natural setting by which the transfer of house dust mites to selected clothing fabrics could be assessed, some limitations of the study should be mentioned. In natural settings, mite populations can vary substantially and are governed by a host of external variables, including substrate type,³⁰ temperature and relative humidity,^{31–33} food availability,³⁰ and species-species interactions.²⁸ In addition, although electrostatic charge was not measured for the fabric types in the study, this parameter has been previously identified as having the potential to influence particle resuspension in clothing fabrics.³⁴ The amount of static charge can be dependent on factors such as fabric type, friction due to surface agitation, and ambient humidity. On the basis of the pile lengths of the 3 fabrics and the potential for triboelectric charging due to contact among individual fibers within a particular fabric, it is assumed that the fleece fabric would carry the largest static charge and smooth cotton the smallest static charge. However, the potential for static charge accumulation on fabrics was minimized during the actual experiments by the precise alignment of the mite-loaded and receiving fabrics, thus preventing agitation of rotary movements.

In nature, mite populations consist of a mixture of both live and dead mites.^{9,27} Because an attempt to accurately represent a natural house dust mite population would invariably be inaccurate, it was decided that using dead mites and live mites in separate treatments ensured reproducibility of the method. Although there were significant effects on transfer efficiencies between the applied contact forces of 50 N and 75 N, it remains unclear whether this trend is likely to continue with increasing or decreasing applied forces. Similarly, although this experiment revealed no effect of duration of contact on transfer efficiencies, these focused on 2 factor levels only, making no inferences for contact durations between 3 seconds and 20 minutes or more than 20 minutes. Although 3 constituents of modern clothing were examined, other synthetic and natural clothing fabrics, such as nylon and wool, were not, which leaves scope for investigation in future studies.

Despite these findings, this research sheds new light on our understanding of the dynamics involved regarding the transfer of house dust mites via clothing, with implications for the transportation and establishment of mite populations in uncontaminated textiles and furnishings. Subject to temperature and relative humidity optima, population doubling times of 24.3 days for *D pteronyssinus* have been recorded.³⁵ Transfer efficiencies for live mites of up to 11.9% were observed in this study, which implies that mite populations could be established relatively quickly in clothing subjected to contact with surfaces bearing mite populations, although the rate of population growth would likely depend on the initial population size transferred and other governing factors, such as food availability, temperature, and relative humidity.

From the point of view of sensitization, the presence of dead mites in car seats and their subsequent transference to clothing may be just as important as live mites. Allergens produced by dust mites are known to persist in the environment for up to several months until they are eventually broken down, presumably by microbial decomposition.²⁸ The allergen pool created by the mites when living may still remain in the bodies of the mites and in their immediate microenvironment for some time after death, hence presenting a sensitization risk. Recent research has identified clothing as a probable source of significant daily allergen exposure, although a reevaluation of quantities of both allergen and mite bodies as risk factors for sensitization in this context is required.²³

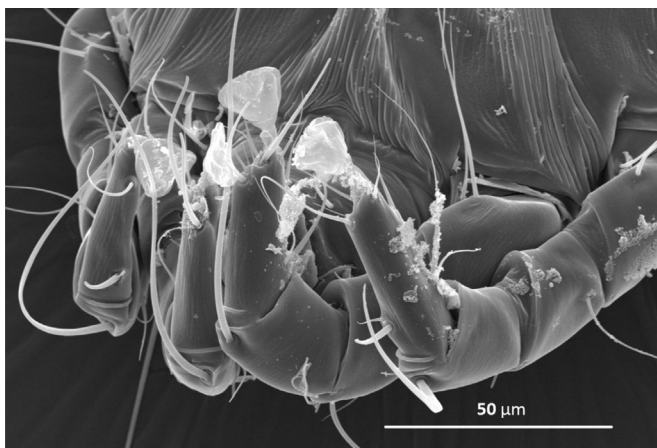


Figure 6. Scanning electron micrograph of *Dermatophagoides pteronyssinus* showing pulvilli at ends of legs. These appendages enable the species to gain a stronger foothold in the substrate.

Nonetheless, the research conducted in this study reveals that house dust mites are transferred to fleece more readily than to plain woven cotton or denim, a point that sensitized persons may need to be aware of in the context of potentially increased allergen exposure associated with this fabric type.

In conclusion, future investigations should determine the effects of fabric type, applied force, and duration of contact at more factor levels than covered in the scope of this study. Different mite loadings and other contaminated material types, such as those derived from house furniture, carpets and bedding, which likely exhibit various combinations of cotton or polyester material and different weave and pile structures, should be investigated with regard to mite transference to uncontaminated fabric types. Finally, the dynamics involved in the transfer of house dust mite allergens should be assessed.

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