

The importance of housing characteristics in determining Der p 1 levels in carpets in New Zealand homes

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Summary

Background A previous study of homes in Wellington, New Zealand showed that having carpets on floors was the most important determinant of floor Der p 1 levels, but there was much unexplained variability between houses in carpet levels.

Objective To determine to what extent housing characteristics might explain this variability in Der p 1 levels between houses.

Methods We returned to a selection of houses with carpets and sampled living room dust from 1 square metre for 1 min and from the whole floor at 5 m² per min. Der p 1 levels were estimated by double monoclonal antibody ELISA and are expressed as geometric mean µg/g and µg/m² (95% confidence intervals). Questionnaires were used to collect information on housing characteristics.

Results Der p 1 levels were significantly higher in the 1 square metre sample (40.0, 31.9–50.2 µg/g; 53.4, 41.4–68.9 µg/m²) than in the whole room (25.8, 21.3–31.1 µg/g; 5.3, 3.8–7.4 µg/m²). However, results from the different sampling methods were correlated ($r = 0.51$, $P = 0.001$ for µg/g and $r = 0.58$, $P = 0.001$ for µg/m²). After controlling for possible confounders, houses with insulation or a room or garage below the living room had approximately half the Der p 1 concentration ($P = 0.05$ for both samples) and the amount of Der p 1 per m² ($P = 0.004$ for the 1 square meter sample, $P = 0.06$ for the whole room sample) than houses without these features. Having more than two children was associated with higher levels of Der p 1 in 1 square meter, significant ($P = 0.05$) for µg/m². Carpet underlay less than 8 mm thick was associated with an almost 3-fold increase in µg/m² Der p 1 ($P = 0.03$) and a 1.6-fold increase in µg/g Der p 1 ($P = 0.08$) in the whole room sample, when compared with thicker carpet underlays.

Conclusion The presence of insulation is the single most important housing characteristic explaining the between-house variability in Der p 1 levels on carpeted living room floors.

Keywords: housing characteristics, insulation, carpet characteristics, Der p 1

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Introduction

Although the role of dust mite allergen in the development of asthma is still unclear, it is well recognized that Der p 1 level is associated with dust mite sensitization [1,2] and

asthma exacerbations in those with existing asthma [3]. A previous study by our group found very high levels of Der p 1 in beds (46.6 µg/g) and on living room floors (25.5 µg/g) in Wellington homes [4]. This is of concern in New Zealand where there is a 30% prevalence of current wheeze at age 13–14 years [5]. In this previous study [4], we established that carpeted floors, carpets more than 1 year old, the autumn season and increasing family size were the

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most important factors explaining floor Der p 1 levels. However, there was much unexplained variation between houses. Although humidity is an important determinant of dust mite survival [6], we did not find an association between humidity measured on the carpet surface and Der p 1 concentration, and concluded that the method used may not have accurately reflected the microenvironment that mites inhabit at carpet bases. In contrast to the high levels of Der p 1 we found in domestic dwellings, we have found Der p 1 levels in public buildings in Wellington to be low ($0.58 \mu\text{g/g}$), even on carpeted floors ($0.95 \mu\text{g/g}$) [7], suggesting that factors more commonly found in public buildings may limit mite population growth.

The aim of the present study was to return to a sample of the previously studied domestic houses with carpets to determine to what extent housing construction, carpet and site characteristics might influence the microenvironment of the dust mite and further explain variability in Der p 1 levels on carpets. As some of this variability will be due to the choice of sampling site within a room, we were also interested in determining the association between a 1 square meter sample and a sample taken from the whole room. A further aim was to confirm prospectively our previous cross-sectional findings for effect of season on Der p 1 levels. Finally, this study aimed to determine whether the level of Der p 1 in these houses had changed over the 4 years since the original study.

Methods

The original study, conducted in 1994, included 470 houses. The present study was conducted between March 1998 and February 1999, 4 years after the original study. The sampling frame for the present study was based on the 355 houses where dust was originally sampled from carpet only. Houses where the sample represented a composite carpet/rug sample were excluded. The data were ranked according to previous Der p 1 levels and those with the highest and lowest levels of Der p 1 were selected to be part of the present study until the required sample size was achieved. Ineligible respondents were replaced with the respondent with the next highest/lowest Der p 1 level. Eligibility criteria ensured that respondents had not moved house, replaced or removed the floor cover, installed central or under-floor heating, or fitted insulation since the original study. Houses where the living room now functioned as another room in the house were also excluded. The selection procedure was stratified by month, with visits taking place in the same season as previously. The study began in autumn and repeat 1 meter square (but not whole room) dust samples were taken from this subset of houses ($n = 20$) in each season over a 12-month period.

We collected two samples of living room dust. An area

of 1 square meter was marked out in the centre of the living room, and was sampled for 1 min using a Hitachi 1100 watt vacuum cleaner with the dust collected in a nylon sock inserted onto the furniture attachment of the vacuum (as previously). This vacuum cleaner could not be used for the collection of the larger whole floor sample as disposable vacuum bags could not be used with this model. Instead, a later model (Hitachi super 4700, 1300 watt) was used for the sampling of dust from the whole accessible floor area of the living room, using a standard vacuum attachment and a new disposable bag for each sample. The rate of collection, at 5 m^2 per min, was standardized across the two field workers and was intended to represent normal household cleaning behaviour. The area sampled was measured so that the Der p 1 levels could be expressed as $\mu\text{g/m}^2$, as well as $\mu\text{g/g}$. After collection, dust was frozen to kill the mites and later sieved ($425 \mu\text{m}$) with the fine dust used to estimate Der p 1 levels using a double monoclonal antibody ELISA [8].

Field workers collected questionnaire information on building materials, insulation (to prevent heat loss) in walls, ceilings or under floors, condensation, damp and mould, hours of sun, position of living room in relation to other rooms in the house, vacuum cleaner make, model and motor size, frequency and recency of vacuuming, steam cleaning or shampooing, carpet and underlay material, type (woven or tufted) and age, and occupancy. Information on factors, such as heating, that had not shown an association with Der p 1 in our previous study of the same homes were not collected this time. The depths of the carpet pile and underlay were measured by inserting a probe. In addition, the field workers checked for damp and mould in the living room, the lie of the ground under and around the house and, using a compass, measured the direction the living room faced. For living rooms situated on the ground floor, the distance between the living room floor and the ground was measured.

Data-loggers were used to record temperature and relative humidity at the carpet base and in the air at 15-min intervals over a minimum period of 24 h, using a sensor device [9]. One pair of temperature and relative humidity sensors were positioned at the base of the carpet and another pair were suspended in the air approximately 1 m from the floor.

Although houses were selected to represent a bimodal distribution of Der p 1 levels, the level of Der p 1 had regressed towards the mean so that in the present study there was no longer a distinct division between those houses with previously high Der p 1 levels and those houses with previously low Der p 1 levels. Instead Der p 1 was log-normally distributed. Thus our original intention to define the outcome as a dichotomous variable based on previous Der p 1 level was no longer

appropriate. Instead, for dichotomous exposure variables, geometric mean Der p 1 levels and 95% confidence intervals (95% CI) were estimated for each subgroup of that variable with *t*-tests used to measure the significance of the differences. Results were expressed as $\mu\text{g/g}$ and $\mu\text{g/m}^2$ for the 1 square meter and the whole room samples. Pearson's correlation coefficient was used to estimate correlations between Der p 1 from the different sites and between Der p 1 expressed as $\mu\text{g/g}$ (the concentration) and $\mu\text{g/m}^2$ (a measure of the amount of Der p 1 per m^2). Mean, minimum and maximum temperature and relative humidity in the carpet and the air were calculated for each house and their distributions across houses found to be normally distributed. Der p 1 levels were estimated for each temperature and relative humidity subgroup defined according to quartile values.

Ethical approval for the study was granted by the Wellington Ethics Committee.

Results

One hundred and one respondents (28% of the original study group with carpets) selected as having high Der p 1 levels were approached. Of these, 35 had moved house, nine had changed the floor cover, one had installed central heating, and 14 refused, leaving 42 eligible participants. One hundred and two respondents (29% of the original study group with carpets) selected as having low Der p 1 levels were approached. Of these, 37 had moved house, 21 had changed the floor cover, one had fitted insulation, one living room had become a bedroom, and six refused, leaving 36 eligible participants.

After the exclusion of ineligible respondents, the response rate was 75% among those selected as having previously high Der p 1 concentrations, and 85% among

those selected as having previously low Der p 1 concentrations.

Table 1 shows the geometric mean levels, 95% CI, range and geometric standard deviations (GSD) for the 1 square meter and whole room samples expressed as $\mu\text{g/g}$ and $\mu\text{g/m}^2$ and the geometric mean weights of fine dust collected. The concentration of Der p 1 was significantly higher ($P = 0.0001$) in the 1 square meter sample than in the whole room. Although the mean area sampled for the whole room was 16 square meters, the geometric mean amount of dust from the whole room was less than three times that collected from the 1 square meter sample. This is reflected in the significantly smaller ($P = 0.0001$) amount of Der p 1 per m^2 found in the whole room than in 1 square meter. From the 1 square meter sample, dust weight was not related to Der p 1 concentration, whereas from the whole room sample there was a small but significant association ($r = 0.34$, $P = 0.002$) between dust weight and Der p 1 concentration. Pearson's correlation coefficient between log Der p 1 based on 1 square meter and log Der p 1 based on the whole room was 0.51 ($P = 0.0001$) for $\mu\text{g/g}$ and 0.58 ($P = 0.0001$) for $\mu\text{g/m}^2$. The correlation between log Der p 1 expressed as $\mu\text{g/g}$ and $\mu\text{g/m}^2$ was 0.82 ($P = 0.0001$) for the 1 square meter sample, and 0.79 ($P = 0.001$) for the whole room sample.

There was a weak ($r = 0.31$) but significant ($P = 0.005$) correlation between the geometric mean levels of Der p 1 collected in 1994 (32.3 $\mu\text{g/g}$) and 1998 (40.0 $\mu\text{g/g}$). In order to establish whether there had been any systematic change in the level of Der p 1 over time we weighted the differences in levels by the distribution of Der p 1 in the original 1994 data set. Although the level of Der p 1 was higher in 1998, the weighted mean of the differences between the 1994 and 1998 samples did not differ significantly from zero.

In the subsample of 20 homes that were sampled in each

Table 1. Geometric mean $\mu\text{g/g}$ and $\mu\text{g/m}^2$ Der p 1 and weight of dust from the 1 square meter sample and the whole room sample

	<i>n</i> = 78	Geometric mean $\mu\text{g/g}$	95% CI	Range	GSD
1 square meter		40.0	31.9–50.2	1.9–520.6	2.7
Whole room		25.8	21.3–31.1	2.1–205.9	2.3
	<i>n</i> = 78	Geometric mean $\mu\text{g/m}^2$	95% CI	Range	GSD
1 square meter		53.4	41.4–68.9	4.8–1610.9	3.1
Whole room		5.3	3.8–7.4	0.2–307.3	4.4
	<i>n</i> = 78	Geometric mean weight (g)	95% CI	Range	GSD
1 square meter		1.3	1.2–1.6	0.2–11.2	1.9
Whole room		3.1	2.5–3.9	0.4–57.9	2.6

season, higher levels in 1 square meter were measured in summer (31.1 µg/g, 17.6–55.0, 38.6 µg/m², 19.8–75.1) and autumn (30.3 µg/g, 17.2–53.5, 40.9 µg/m², 22.4–74.8) than winter (24.4 µg/g, 13.6–43.7, 32.1 µg/m², 16.9–61.0) and spring (22.7 µg/g, 12.5–41.4, 28.8 µg/m², 15.1–54.8) but differences did not reach significance, possibly due to the small numbers of houses with repeat samples.

Housing factors

Table 2 shows the geometric mean Der p 1 levels (µg/g and µg/m²) for the 1 square meter and the whole room samples for those housing variables that showed associations at a significance level of $P \leq 0.1$. The presence of floor insulation, most commonly sisalation paper (foil), was associated with significantly lower levels of µg/g and µg/m² Der p 1 for both samples. Having a room or a garage below the living room, rather than a basement or ground, was associated with significantly lower levels of Der p 1 in the 1 square meter sample only. These associations became stronger and significant for all measures of Der p 1 when houses with insulation or a room or garage below the living room were compared

with houses without any of these features. The presence of wall insulation, most commonly fibreglass batts, was also associated with lower levels of Der p 1 significant for the 1 square meter sample. The geometric mean dust weights were non-significantly lower for both samples in the presence of insulation.

Houses built since 1978 had lower levels of Der p 1 compared with older houses for µg/g Der p 1 based on the 1 square meter sample, and µg/m² Der p 1 based on the whole room sample ($P = 0.09$ for both samples) (Table 2).

Timber wall construction was used for 65% of floors and 68% of outside walls. Based on the 1 square meter sample, timber floor construction was associated with non-significantly higher Der p 1 levels (45.5 µg/g or 62.2 µg/m²) than floors constructed with concrete (24.1 µg/g or 34.8 µg/m²) or chip or particle board (32.9 µg/g or 41.1 µg/m²), but there were no differences based on the whole floor sample. The geometric mean dust weight collected in the 1 square meter sample was the same (1.4 g) for timber and concrete floor constructions. Similarly, timber outside wall construction was associated with higher Der p 1 levels than all other building materials; for the 1 square meter sample, 44.0 µg/g or 56.4 µg/m² compared with 25.9 µg/g or

Table 2. Geometric mean Der p 1 levels for the 1 square meter sample and the whole room sample for those housing variables that showed significant ($P < 0.10$) associations for any outcome measure

		1 square meter sample		Whole room sample	
	<i>n</i> (=78)	Geometric mean μg/g	Geometric mean μg/m ²	Geometric mean μg/g	Geometric mean μg/m ²
<i>Any floor insulation#</i>					
Yes	25	26.1**	28.8***	18.8**	3.1**
No	47	42.9	62.1	27.8	6.6
<i>Under living room#</i>					
Room or garage	21	25.0***	34.8**	21.6	3.9
Basement or ground	57	46.6	62.5	27.5	7.0
<i>Insulation/room vs. other</i>					
Room, garage, insulation	32	27.5***	31.8****	20.3**	3.2***
other	46	51.9	76.7	30.4	7.5
<i>Any wall insulation#</i>					
Yes	36	31.3**	38.7**	23.4	4.5
No	30	48.7	69.0	26.6	6.0
<i>Visible damp on walls</i>					
Yes	2	142.8	338.4**	47.5	11.9
No	76	38.7	50.9	25.3	5.2
<i>Age of house#</i>					
Pre-1978	55	43.6	58.6	21.3	6.08
Since 1978	20	28.2*	34.1	20.9	3.03*

* $P < 0.10$, ** $P < 0.05$, *** $P < 0.001$, **** $P < 0.0001$.

#Numbers do not add up to total *n* because 'don't know' responses are not shown.

38.2 $\mu\text{g}/\text{m}^2$ for walls made of hardiplank (wood fibre reinforced cement board), the next most common type of wall construction (17% of homes), but these differences were not significant.

Carpet and cleaning characteristics

Table 3 shows that, based on the 1 square meter sample, greater concentrations of Der p 1 were found if the carpet was tufted rather than woven ($P = 0.08$), or had a pile length of more than 4 mm, compared with a shorter pile ($P = 0.08$). However, woven carpets had significantly more Der p 1/ m^2 in the whole room sample. Carpets with underlay less than 8 mm thick were also associated with a higher concentration ($P = 0.07$) and amount of Der p 1/ m^2 ($P = 0.04$) in the whole room. Wool carpets, compared with synthetic, had a higher concentration of Der p 1 in 1 square meter ($P = 0.07$). Carpet age did not affect Der p 1 level ($\mu\text{g}/\text{g}$ or $\mu\text{g}/\text{m}^2$), possibly because the eligibility criteria required that all carpets were at least 4 years old (not shown in table).

Homes with a vacuum cleaner motor size of 1000 watts or less had more Der p 1/ m^2 than homes with more powerful vacuum cleaners, but there was a smaller effect for the concentration of Der p 1 ($\mu\text{g}/\text{g}$) (Table 3). In contrast, the age of the vacuum cleaner, the presence of a HEPA-filter or a disposable bag made little difference to the level of Der p 1.

Only a small number of respondents ($n = 3$) reported vacuuming less often than once a week, but levels of Der p 1 in these homes were consistently higher than levels in homes with more frequent vacuuming (Table 3). Higher levels of Der p 1 were found in 1 square meter in association with steam cleaning in the last 12 months (73.4 $\mu\text{g}/\text{g}$ compared with 39.1 $\mu\text{g}/\text{g}$ ($P = 0.29$), 120.1 $\mu\text{g}/\text{m}^2$ compared with 51.7 $\mu\text{g}/\text{m}^2$ ($P = 0.20$)) and the whole room (57.2 $\mu\text{g}/\text{g}$ compared with 24.9 $\mu\text{g}/\text{g}$ ($P = 0.09$), 25.1 $\mu\text{g}/\text{m}^2$ compared with 5.0 $\mu\text{g}/\text{m}^2$ ($P = 0.06$)).

Households with three or more children had significantly higher levels of Der p 1 in the 1 square meter sample than households with fewer children but these differences did

Table 3. Geometric mean Der p 1 levels for the 1 square meter sample and the whole room sample for those carpet, cleaning and occupancy variables that showed significant ($P = < 0.10$) associations for any outcome measure

		1 square meter sample		Whole room sample	
	<i>n</i> (=78)	Geometric mean μg/g	Geometric mean μg/m ²	Geometric mean μg/g	Geometric mean μg/m ²
<i>Carpet type#</i>					
Tufted	59	43.4*	51.5	24.9	4.1
Woven	15	25.9	48.8	24.9	10.8**
<i>Pile depth</i>					
0–4 mm	25	30.1	58.9	22.7	6.8
5–12 mm	53	45.8*	51.8	27.3	4.7
<i>Depth of underlay</i>					
0–7 mm	10	37.1	59.5	40.3*	12.8**
8–13 mm	68	40.5	52.6	24.1	4.6
<i>Carpet material#</i>					
Wool	49	44.9*	51.3	27.6	4.9
Synthetic	10	22.6	37.6	23.6	6.7
<i>Vacuum motor size#</i>					
< = 1000 watts	35	48.0	68.1*	29.2	7.2*
1001 + watts	42	33.5	42.2	22.9	4.0
<i>Frequency of vacuuming</i>					
< once a week	3	82.1	136.5	78.1**	18.2
= > once a week	75	38.9	51.4	24.6	5.0
<i>Number of children</i>					
1–2	45	33.5	40.6	22.7	4.2
3+	33	51.0**	77.6**	30.5	7.1

* $P = < 0.10$, ** $P = < 0.05$, *** $P = < 0.001$, **** $P = < 0.0001$.

#Numbers do not add up to total n because 'don't know' responses are not shown.

not reach significance for the whole room sample (Table 3).

The slope of the ground under the house, the lie of the surrounding ground with respect to hills and the direction that the living room faced did not significantly affect Der p 1 levels.

Damp

Reported or observed damp or mould on living room floors or walls tended to be associated with non-significantly higher levels of Der p 1, with the association becoming significant for visible damp on living room walls and the amount of Der p 1 in the 1 square meter sample (Table 2). Hours of summer sun, winter sun, sun at time of dust collection or mean summer/winter hours of sun were not significantly associated with Der p 1 level, although Der p 1 levels tended to be higher with fewer hours of sun. The proximity of the bathroom or laundry to the living room appeared to have no influence on living room Der p 1 level. The presence of a dehumidifier in the living room was non-significantly associated with an almost two-fold higher concentration of Der p 1 from the 1 square meter sample only.

Relative humidity and temperature

The mean air relative humidity across all homes was 63.7%, the mean minimum air relative humidity was 45.6% and the mean maximum air relative humidity was 73.2%. The mean carpet relative humidity across all homes was 66.2%, the mean minimum carpet relative humidity was 53.9%, and the mean maximum carpet relative humidity was 70.7%. Every home had at least one recording of 50% or more relative humidity. Using quartiles as cut-off points, there was no association between the mean, maximum and minimum relative humidity in the air or the carpet and $\mu\text{g/g}$ or $\mu\text{g/m}^2$ Der p 1. There was also no correlation between relative humidity and Der p 1 level. However, having a room or garage below the living room was associated with a lower mean carpet relative humidity (63%) than having a basement or the ground (67%) ($P = 0.10$). Insulated floors were also associated with a lower mean carpet relative humidity (62%) than non-insulated floors (68%) ($P = 0.01$).

The mean air temperature across all homes was 18.8 °C, the mean minimum air temperature was 15.1 °C and the mean maximum air temperature was 24.3 °C. The mean carpet temperature was 19.4 °C, the mean minimum carpet temperature was 16.5 °C, and the mean maximum carpet temperature was 24.6 °C. Using quartiles as cut-off points, we found no association between the mean, minimum or maximum temperature in the air or the carpet and Der p 1

level. There was also no correlation between temperature and Der p 1 level. Insulation had little effect on the temperature of the carpet.

Multivariate analysis

The multivariate analysis was conducted separately for each site sampled (1 square meter and the whole room) and for both the concentration ($\mu\text{g/g}$) and amount of Der p 1 ($\mu\text{g/m}^2$) (Table 4). In each case, those variables that were associated with Der p 1 in the univariate analysis at the 0.10 significance level were included in the model. The variable for insulation was defined to contrast homes with floor insulation, including insulation provided by a room or garage below the living room, with those homes without any form of insulation.

When the concentration of Der p 1 ($\mu\text{g/g}$), based on 1 square meter, was the dependent variable, the above insulation variable was combined in a model with variables for the age of house (pre/post 1978), total number of children (1–2 vs. 3+), type of carpet (tufted or woven), carpet pile depth (0–4 mm vs. 5–12 mm) and carpet material (wool vs. synthetic). Table 4 shows that the presence of insulation, including that provided by a room or garage, was the only factor that remained statistically significantly ($P = 0.05$) associated with Der p 1 concentration. The marginally significant increased risk associated with woollen carpets was unchanged. The addition of the variable for dust weight to the model showed that these effects were independent of the weight of dust collected.

The model for the amount of Der p 1/ m^2 based on the 1 square meter sample included the above variables for insulation and total number of children, and an additional variable, vacuum cleaner motor size (< 1000 vs. 1001+ watts). The negative association for the presence of insulation and the positive association for family size with Der p 1/ m^2 remained strong and significant. The association of a lower-powered vacuum cleaner with high levels of Der p 1 reduced slightly but remained marginally significant.

Table 4 also shows that there was a similar protective effect of insulation using the concentration of Der p 1 based on the whole room sample as the dependent variable. Having thin carpet underlay (0–7 mm vs. 8–13 mm) remained marginally associated with higher Der p 1 while the effect of infrequent vacuuming (less than once a week) on Der p 1 concentrations reduced, also becoming only marginally significant. The addition of a variable for dust weight to this model slightly reduced the effect of insulation and carpet underlay on Der p 1 level.

The model for the amount of Der p 1/ m^2 based on the whole room sample included the variables for insulation,

Table 4. Multivariate association of housing factors with Der p 1 ($\mu\text{g/g}$ and $\mu\text{g/m}^2$) in a 1 square meter and whole room sample

	1 square meter sample		Whole room sample	
	Ratio of geometric mean $\mu\text{g/g}$ (95% CI) [†]	Ratio of geometric mean $\mu\text{g/m}^2$ (95% CI) [‡]	Ratio of geometric mean $\mu\text{g/g}$ (95% CI) ^δ	Ratio of geometric mean $\mu\text{g/m}^2$ (95%) ^α
<i>Geometric mean Der p 1 (95% CI)</i>	40.0 (31.9–50.2)	53.4 (41.4–68.9)	25.8 (21.3–31.1)	5.3 (3.8–7.4)
<i>Insulation/room vs. other</i>				
Yes	0.61 (0.37–1.00)*	0.49 (0.31–0.78)**	0.69 (0.48–1.00)*	0.52 (0.27–1.03)
No	Ref	Ref	Ref	Ref
<i>Age of house</i>				
Pre-1978	1.42 (0.83–2.42)	#	#	1.70 (0.80–3.61)
Since 1978	Ref			Ref
<i>Number of children</i>				
1–2	Ref	Ref	#	#
3 +	1.32 (0.81–2.17)	1.83(1.15–2.92)*		
<i>Carpet type</i>				
Tufted	1.34 (0.70–2.59)	#	#	Ref
Woven	Ref			2.34 (0.55–9.03)
<i>Pile depth</i>				
0–4 m	Ref	#	#	#
5–12 mm	1.46 (0.84–2.54)			
<i>Carpet material</i>				
Wool	1.89 (0.95–3.80)	#	#	#
Synthetic	Ref			
<i>Frequency of vacuuming</i>				
Less than once a week	#	#	2.43 (0.94–6.30)	#
At least once a week			Ref	
<i>Depth of underlay</i>				
0–7 mm	#	#	1.63 (0.95–2.80)	2.90 (1.12–7.46)*
8–13 mm			Ref	Ref
<i>Vacuum motor size</i>				
Up to 1000 watts	#	1.51 (0.96–2.40)	#	1.79 (0.94–3.42)
1001 + watts		Ref		Ref

Not included in model.

[†] Adjusted for presence of insulation/room, age of house, number of children, carpet type, pile depth and carpet material.[‡] Adjusted for presence of insulation/room, number of children and vacuum cleaner motor size.^δ Adjusted for presence of insulation/room, frequency of vacuuming and depth of underlay.^α Adjusted for presence of insulation/room, age of house, carpet type, depth of underlay and vacuum cleaner motor size.* $P < 0.05$, ** $P < 0.01$.

age of house, carpet type, depth of underlay and vacuum cleaner motor size. Thin carpet underlay remained significantly associated with high Der p 1 but the effects of insulation and a low powered vacuum cleaner were reduced to marginal significance.

A separate model was run to determine the independent effects of carpet characteristics (tufted or woven, wool or synthetic, pile and underlay depth, age), frequency of vacuuming, insulation and house age on dust weight. This showed that the only factors significantly associated with high dust levels were woven carpets ($P = 0.004$) and vacuuming less often than every second day ($P = 0.03$).

Houses built pre-1978 had marginally significantly higher ($P = 0.06$) dust weights.

Discussion

The findings from this study suggest that the single most important factor responsible for lower levels of Der p 1 in carpeted domestic dwellings in New Zealand is the presence of floor insulation. Homes that did not have insulation fitted but had a room or a garage below the living room, or a thick layer of underlay below the carpet, also had lower levels of Der p 1 in at least one sample type. It

appears that these characteristics also have an insulating effect, possibly by increasing the barrier between the carpet and ground moisture. The higher relative humidity found in carpets without insulation below suggests that insulation results in a drier environment, less conducive to mite proliferation. However, we did not find any association between relative humidity (or temperature) and Der p 1 level. Our findings for insulation are, however, consistent with van Strien *et al.* [10] who showed three times the amount of Der p 1 on non-insulated smooth floors with rugs compared with insulated floors. In contrast to our finding that having a basement below the living room is associated with higher Der p 1, Munir *et al.* [11] have shown that homes with basements have lower Der p 1. In our study a basement was generally unlined and without a solid floor, thus it would not provide a barrier between the living room floor and ground moisture. A basement may have been a more solid room-like structure in the study by Munir *et al.* [11].

In the whole room sample, the positive association between dust weight and Der p 1 concentration explained some of the effect of insulation on Der p 1, possibly because non-insulated floors allow more airflow from below and thus more dust. However, for the 1 square meter sample, dust weight was not related to Der p 1 concentration and did not modify the effect of insulation.

Houses built before 1978 tended to have higher levels of Der p 1. Since 1978 building regulation standards have recommended that insulation be fitted in all new homes but these were not enforced universally until the 1990s. Thus we found six houses built since 1978 with living rooms situated immediately above the ground but without floor insulation and therefore were able to establish that older houses had non-significantly higher Der p 1 that was independent of the effect of insulation. Other researchers have also found higher floor Der p 1 in older houses [12, 13].

Other housing characteristics may also influence the floor humidity and thus the level of mites. Our finding of non-significantly higher Der p 1 in association with timber floors may be because ground moisture acts directly on timber floors, whereas with concrete slab floors the damp proof course (a layer of polythene) provides a barrier. Another possible explanation, that timber floors allow more air movement during sampling, is unlikely since the amount of dust collected from both floor constructions was the same. Furthermore our findings are consistent with those of other researchers. In a study by van Strien *et al.* [10], among a subset of houses with carpets, wooden floors were shown to have significantly greater concentrations of Der p 1. Similarly Dharmage *et al.* [13] have shown that in Australia wooden floors on stumps and weather board walls have been associated with higher Der p 1 levels, with the authors suggesting that there may be greater exposure to

underground moisture with wooden floors compared with concrete slab flooring. However, in another Australian study [12] significantly higher levels of Der p 1 have been found in association with slab floors.

The higher levels of Der p 1 found in association with steam cleaning suggest that domestic steam cleaners may actually be responsible for increasing the level of Der p 1, possibly because the temperature achieved with domestic cleaners is insufficient to kill the mites while the introduction of water during the process increases their viability by raising carpet humidity. However, only three respondents had steam cleaned their carpets in the last 12 months. In contrast, a prospective study by our group [14] has shown a reduction in Der p 1 levels using superheated steam cleaners.

After controlling for confounding, woollen carpets had marginally significantly higher concentrations of Der p 1 for the 1 square meter sample only. Given that substantial measurement error is likely to surround these estimates, which were based on questionnaire responses, the true risk may be larger. Other researchers have also shown higher Der p 1 levels associated with woollen carpets [12,13,15].

Having a low powered vacuum cleaner was associated with a greater amount of Der p 1 per m², but not with Der p 1 concentration, presumably because the amount of Der p 1 per m² is influenced by the weight of the total dust collected, with relatively more dust available for collection from homes with lower powered vacuum cleaners. This was true for the whole room sample where we collected a geometric mean level of 3.9 g of dust from homes with less powerful vacuum cleaners and 2.6 g from homes with more powerful vacuum cleaners ($P = 0.06$). However, the difference was small for the 1 square meter sample (1.4 g vs. 1.3 g).

Our finding for a greater concentration of Der p 1 in homes with three or more children confirms our earlier finding [4] and is also consistent with the findings of other researchers [10] and may reflect increased skin shedding (or other food sources) with more children.

It is well established that dust mites only thrive in conditions of high relative humidity [6]. This relationship for humidity has been frequently reported in findings from epidemiological studies in other countries [10,11,16,17]. However, it has been difficult to illustrate in New Zealand even when measurements are taken within the dust mite microenvironment at carpet bases, as in this study. Although our 24-h measurement did not necessarily reflect the longer term climatic conditions that are more likely to influence Der p 1 levels, we suggest that the main reason for this lack of association is due to the ubiquitously high humidity levels within houses in Wellington, New Zealand. All houses had at least one recording of 50% or more relative humidity. Although other researchers [16,17] have

shown significant negative associations between temperature and allergen level, we found no association at all.

The difference in the concentration of Der p 1 between the 1 square meter sample (40.0 µg/g) and the whole room sample (25.8 µg/g) suggests that a 1 square meter sample from the centre of the room may not represent the concentration in the whole room. Several studies [18,19] have shown wide variability in Der p 1 levels within a room. However, the different findings could also be due to the different sampling techniques used for each sample. The rate at which the whole room was sampled was intended to represent normal household vacuuming behaviour and therefore was faster and less intensive than that used for the 1 square meter sample. Thus the dust sampled from the whole room may represent a more superficial layer, where concentrations of Der p 1 have been shown to be lower (Euan Tovey, personal communication). Furthermore, the loss of dust up the tubing of the vacuum cleaner used in the whole room sample may have contributed to the lower weight of dust and the lower amount of Der p 1/m² in the whole room (5.3 µg/m²) compared with 1 square meter (53.4 µg/m²). Thus it is likely that the collection of dust by respondents, as in mail surveys, may underestimate the concentration and total amount of Der p 1 when compared with sampling according to standard procedures by researchers.

Regardless of the method or area sampled, this study has shown that the presence of insulation may approximately halve the level of dust mite allergen on carpeted floors. While this would be an important first step towards healthier houses, even the lower levels of Der p 1 found in association with insulation are high by international standards, and may pose a risk for asthma development and exacerbations. Furthermore, although building standards ensure that insulation is fitted in new homes, most families in Wellington live in older timber homes that pre-date these standards. Improving the indoor environment of these older homes is an important next step in creating healthier houses.

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