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Characterizing Particle Resuspension from Mattresses: Chamber Study

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Detailed Discussion on the Impact of Volunteer Body Mass, Ventilation Rate, and Movement Type

Volunteer Body Mass

Body mass appears to have a minimal impact on *RR*, as shown in Figure S2 (a.) and (b.) (impact of body mass index (BMI) shown in Figure S3). For a dust load of 0.1 g/m^2 and all particle sizes, differences in *RR* between a group of the lightest five volunteers and a group of the heaviest five volunteers was not found to be statistically significant (Tables S5 and S6). However, for several size bins at 1.0 g/m^2, statistically significant differences were determined between the two body mass groups, with a slight increase in *RR* for the lighter group.

Intuitively, resuspension would be expected to increase with body mass (or BMI), however, it is possible that beyond a certain threshold weight, the removal forces induced by body movements in bed is much more dependent on the intensity of the volunteer's movements, the surface vibrations they induce, and their particular movement technique, rather than their body mass alone. For example, a person with a body mass of 55 kg moving in a very abrupt, intense manner may have a similar, or even more pronounced, impact on particle resuspension as a 120 kg individual who moves very gently and cautiously in bed. Qian and Ferro (2008) reported a similar finding, in that resuspension tended to be greater for faster and more intense walking styles compared to less active styles, regardless of the volunteer's body mass.

Chamber Ventilation Rate

The impact of the chamber ventilation rate (0.9, 2.9, and 7.4 h^{-1}) on airborne particle concentrations is shown in Figure S6 (a.). Similar concentration profiles were observed during the movement routine among the three ventilation rates, with the highest concentrations observed for the lowest ventilation rate of 0.9 h^{-1}. As expected, ventilation rate appears to have the most significant impact on particle concentrations during the two decay periods. The particle loss rate ($a + k$) increases with the ventilation rate, thus, improving ventilation may reduce the period over which an occupant is exposed to resuspended particles after cessation of body movements. This is especially important for accumulation-mode particles that have low deposition rates.

RR was not strongly influenced by the chamber ventilation rate (Figure S6 (b.)), with *RRs* at 0.9 h^{-1} similar to those at 2.9 and 7.4 h^{-1}. It is likely that ventilation rates across this range have minimal impact on affecting the mechanisms of resuspension at the surface of the bedding fibers. The ventilation rate, however, may impact mixing conditions, airflow distribution within the chamber, the volunteer's thermal plume, and the spatial uniformity of the particle concentrations in the bulk chamber air (e.g. Rim and Novoselac 2009). The simplified two-compartment *RR* model cannot capture these complex effects. Thus, caution is advised in making conclusions about the impact of ventilation rate on resuspension.

Movement-Specific Resuspension Rates

Figure S4 (a.-e.) show the *RRs* time-averaged over each 2.5 min. movement, M1, M2, M3, M4, and M5. Table S7 lists the *P*-values associated with comparisons between different movements. Movement-specific *RRs* were generally found to be statistically significantly different when comparing M3, 360° rotation of the torso, with M1 (M3 > M1), M2 (M3 > M2), M4 (M3 > M4), and M5 (M3 > M5) (some cases, depending on particle size, movement set, or dust load, were not statistically significant). Similarly, *RRs* for M1, sitting on the mattress, were found to be statistically significantly lower from the other movements for numerous cases. M2, laying in supine position, and M5, 180° rotation of torso from prone to supine position, were not found to be statistically significantly different, whereas differences between M4 with M2 (M4 > M2) and M5 (M4 > M5) were found to be statistically significant for numerous cases. These findings make sense, given that M3 represents the greatest degree of rotation of the torso, M1 is the least intense movement, and M2 and M5 represent similar intensities.

Figure S4 (a.-e.) can be viewed as a time-series of *RR*, from M1 in movement set 1 to M5 in movement set 2. It can be observed that *RR* increases from M1 to M3 in movement set 1, with a slight decrease from M3 to M4, and an additional decrease to M5. Movement set 2 follows a nearly identical trend. The movement routines examined in this investigation were not intended to represent actual sequences of movements sleeping occupants may perform. Furthermore, the order of the specific movements may be a factor. If the 360° rotation of the torso was performed first, rather than third (M3) in the sequence, *RRs* associated with M3 may be greater, given the general decay in resuspension with time, as previously discussed. This decay may partially explain why M4 > M5, even though both movements were very similar.

Figures

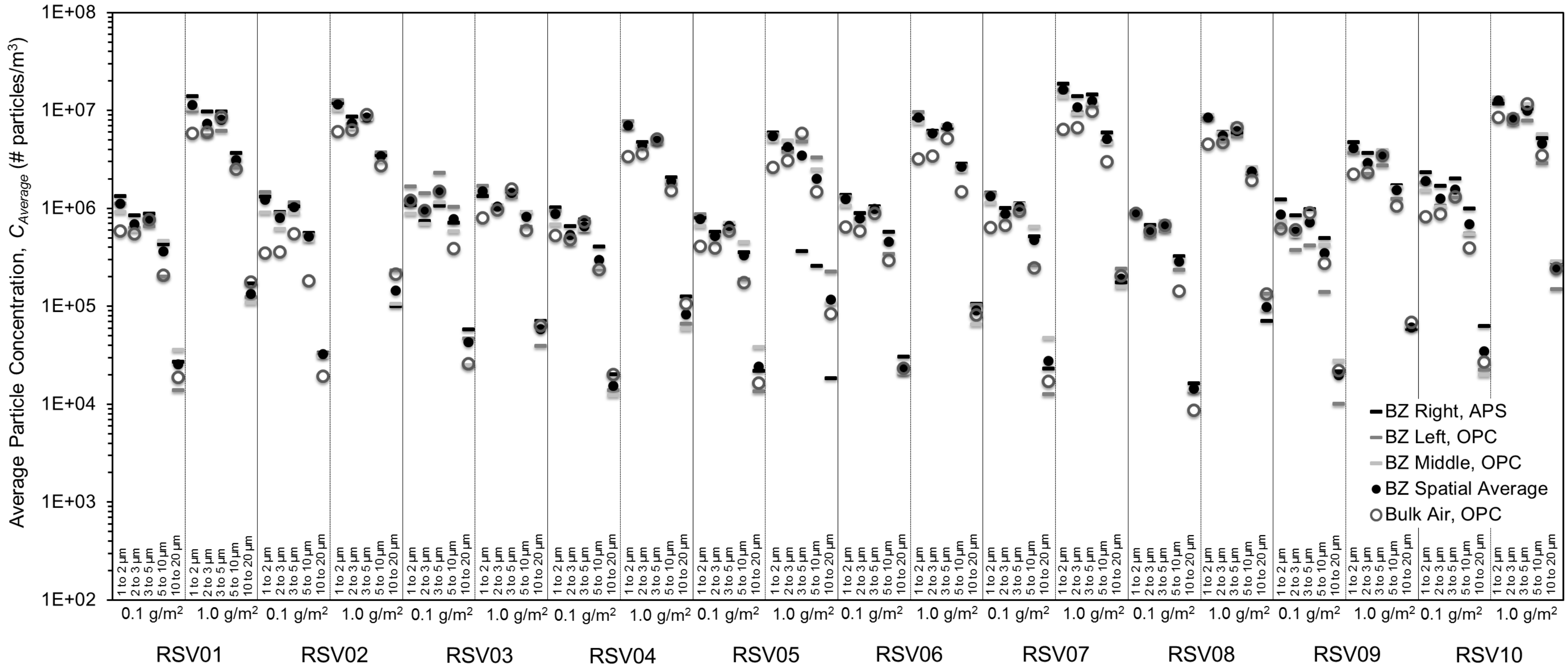

Figure S1: Spatial distribution of average particle concentration over entire movement routine (M1-M5, Set 1) among all sampling locations: Bulk Air, BZ Right, BZ Left, BZ Middle, and spatial BZ average for each experiment, highlighting the source-proximity effect.

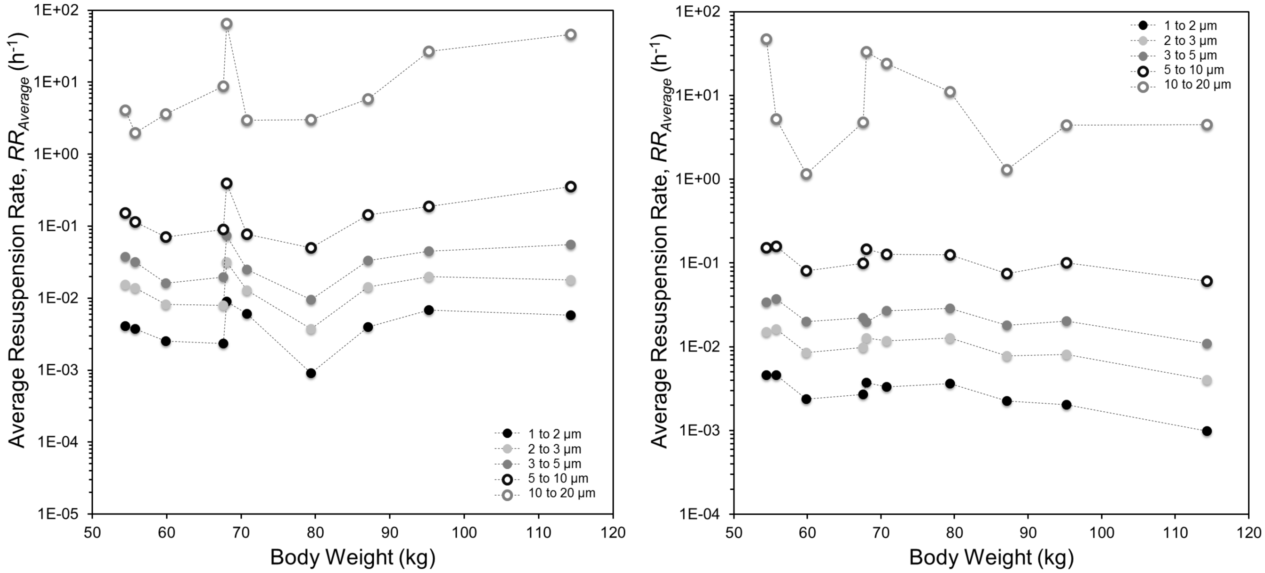

Figure S2 (a.) 0.1 g/m^2 Figure S2 (b.) 1.0 g/m^2

Figure S2: Average resuspension rates (*RR*) over entire movement routine (M1-M5) as a function of volunteer body weight, (a.) 0.1 g/m^2 and (b.) 1.0 g/m^2 dust loads.

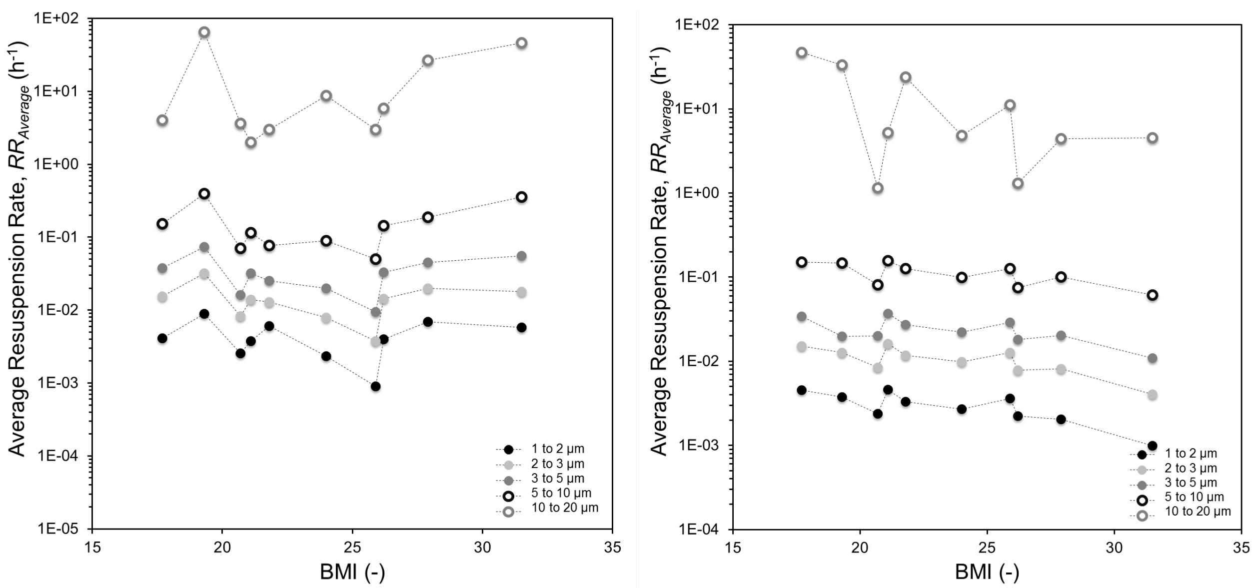

Figure S3 (a.) 0.1 g/m^2 Figure S3 (b.) 1.0 g/m^2

Figure S3: Average resuspension rates (*RR*) over entire movement routine (M1-M5) as a function of volunteer body mass index (BMI), (a.) 0.1 g/m^2 and (b.) 1.0 g/m^2 dust loads.

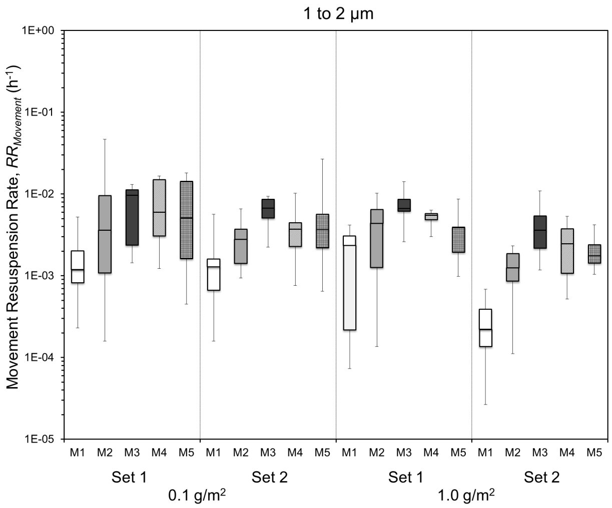

Figure S4 (a.)

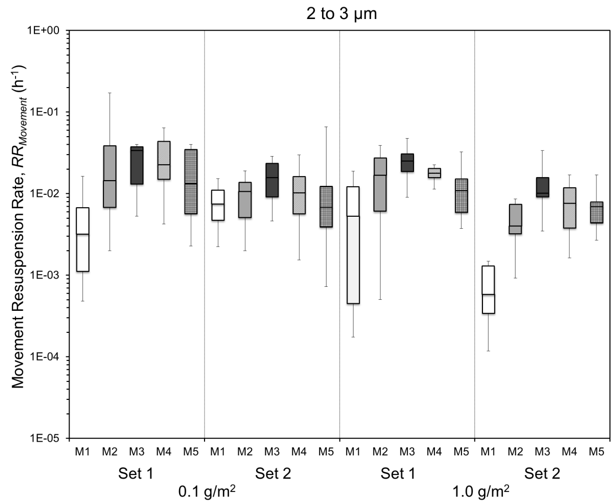

Figure S4 (b.)

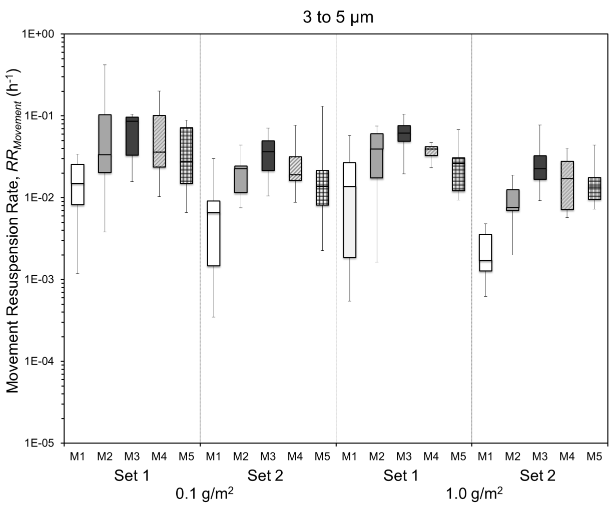

Figure S4 (c.)

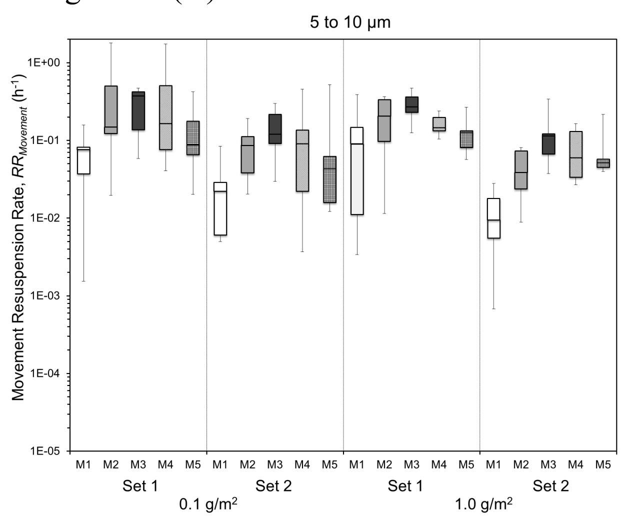

Figure S4 (d.)

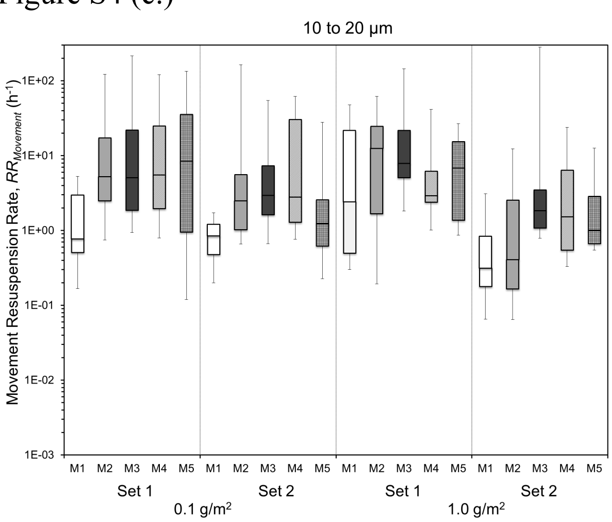

Figure S4 (e.)

Figure S4: Average resuspension rates (*RR*) among 10 volunteers for each individual movement (M1, M2, M3, M4, M5), (a.): 1 to 2 µm, (b.) 2 to 3 µm, (c.) 3 to 5 µm, (d.) 5 to 10 µm, and (e.) 10 to 20 µm. Box plots represent interquartile range, whiskers represent the 5^{th} and 95^{th} percentiles, and shading represents specific movements (M1-M5), as denoted on the x-axis.

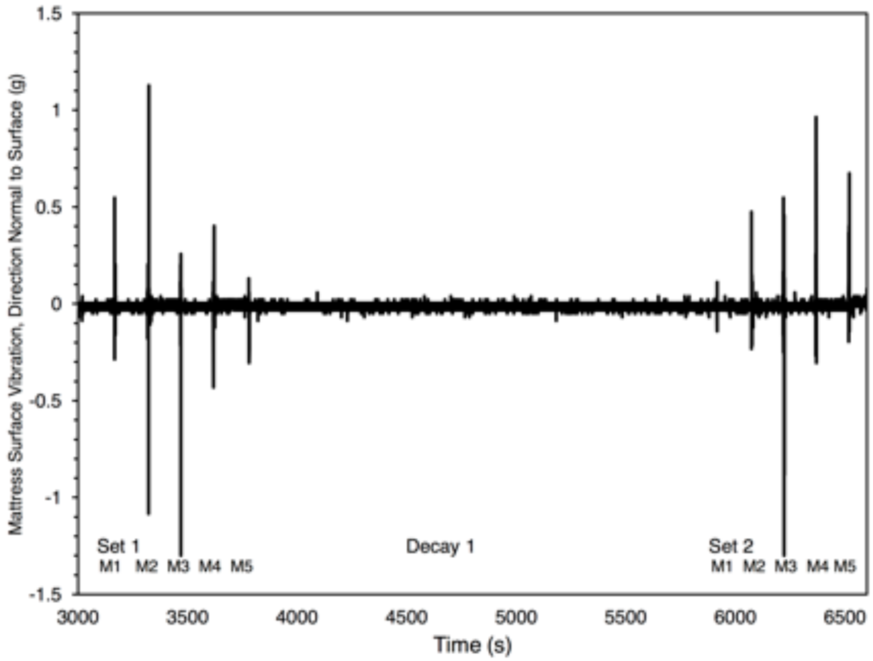

Figure S5 (a.)

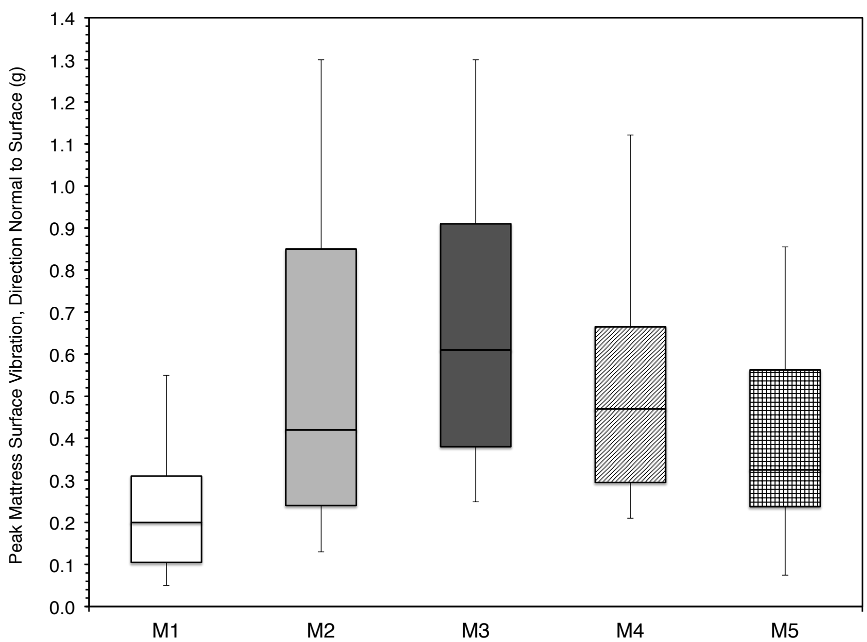

Figure S5 (b.)

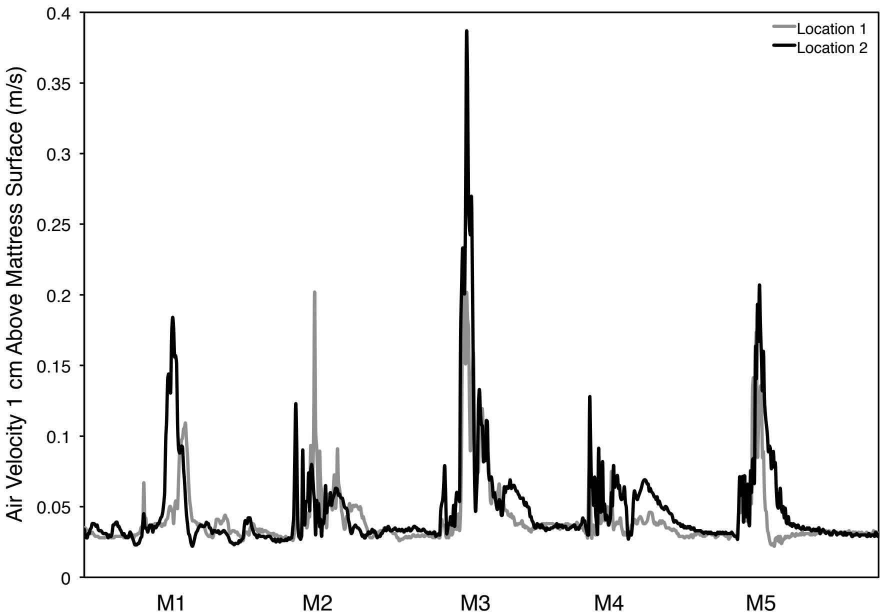

Figure S5 (c.)

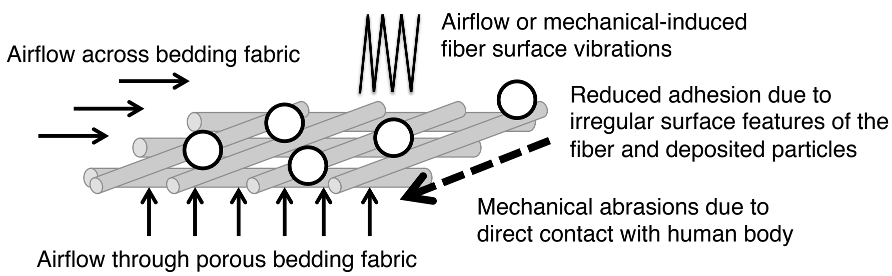

Figure S5 (d.)

Figure S5: (a.) Example profile of mattress surface vibrations during a resuspension experiment, (b.) the distribution of peak mattress surface vibrations (direction normal to surface, magnitude) across all resuspension experiments for each movement, (c.) example of air velocity 2.5 cm above mattress surface, and (d.) possible mechanisms that may be responsible for particle resuspension from the mattress and bedding fabric surfaces. Box plots represent interquartile range and whiskers represent the 5th and 95th percentiles.

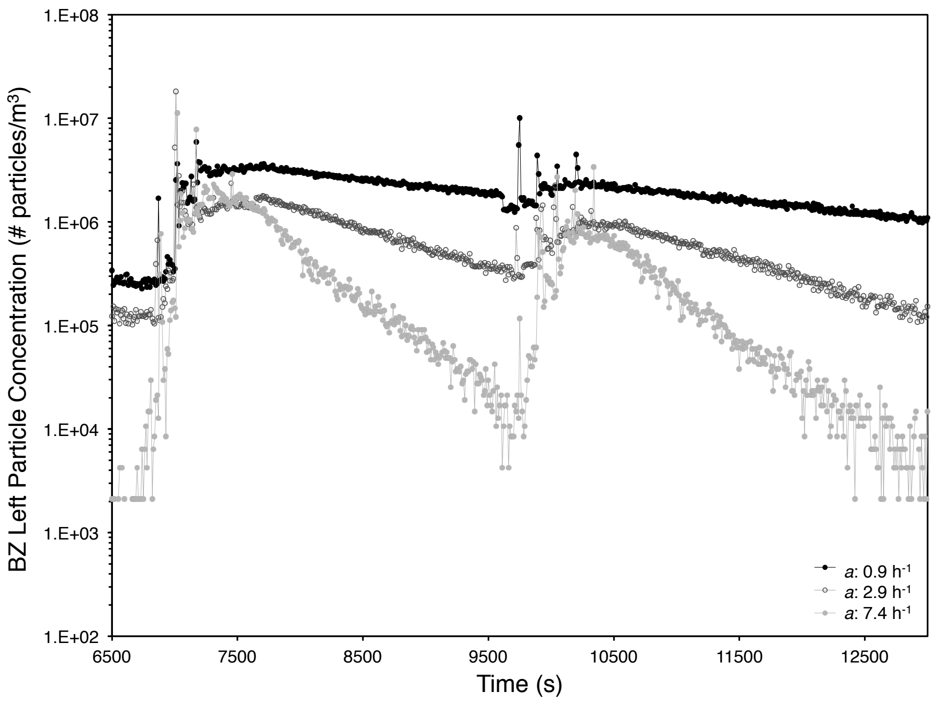

Figure S6 (a.)

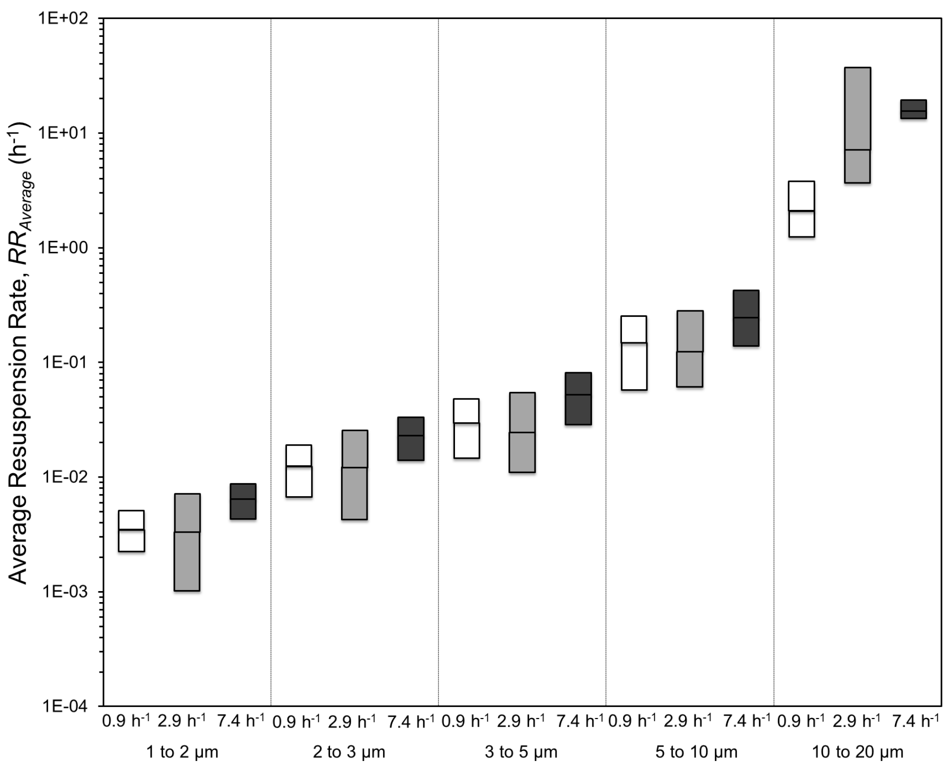

Figure S6 (b.)

Figure S6: (a.) impact of ventilation rate on particle concentration during movement routine and decay periods, (b.) impact of ventilation rate on average resuspension rate (*RR*) over entire movement routine (M1-M5) for two volunteers (RSV01 & RSV02). Box plots represent interquartile range and shading represents ventilation rate, as denoted on the x-axis.

Tables

Table S1: Experimental matrix

Volunteer ID	Weight (kg)	Height (cm)	BMI[1]	Dust Load, L_0 (g/m^2) Nominal[2]	Actual[3]
RSV01	68	188	19.2	0.1 (a = 0.9 h^{-1})	0.14±0.06
				0.1 (a = 2.9 h^{-1})	0.08±0.03
				0.1 (a = 7.4 h^{-1})	0.06±0.02
				0.5	0.56±0.17
				1	1.12±0.17
RSV02	79	175	25.8	0.1 (a = 0.9 h^{-1})	0.14±0.06
				0.1 (a = 2.9 h^{-1})	0.20±0.09
				0.1 (a = 7.4 h^{-1})	0.09±0.05
				0.5	0.58±0.13
				1	1.12±0.22
RSV03	114	191	31.2	0.1	0.10±0.08
				1	0.98±0.17
RSV04	68	168	24.1	0.1	0.12±0.06
				1	0.85±0.10
RSV05	95	185	27.8	0.1	0.10±0.04
				1	0.90±0.09
RSV06	60	170	20.8	0.1	0.10±0.04
				1	0.91±0.05
RSV07	56	163	21.1	0.1	0.10±0.05
				1	1.19±0.18
RSV08	71	180	21.9	0.1	0.11±0.04
				1	1.07±0.12
RSV09	87	182	26.3	0.1	0.08±0.04
				1	1.01±0.14
RSV10	54	175	17.6	0.1	0.11±0.04
				1	1.26±0.17

[1]: Calculated with The National Heart, Lung, and Blood Institute's (NHLBI) Body Mass Index (BMI) calculator.
[2]: All experiments were performed at a chamber ventilation rate, a, of 2.9 h^{-1}, unless otherwise specified.
[3]: Mean of the nine microscope slides ± standard deviation (SD)

Table S2: Impact of particle size on average resuspension rate (*RR*) and intake fraction (*iF*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

		Movement Set 1				Movement Set 2			
		1 to 2 µm < 2 to 3 µm	2 to 3 µm < 3 to 5 µm	3 to 5 µm < 5 to 10 µm	5 to 10 µm < 10 to 20 µm	1 to 2 µm < 2 to 3 µm	2 to 3 µm < 3 to 5 µm	3 to 5 µm < 5 to 10 µm	5 to 10 µm < 10 to 20 µm
Dust Load: 0.1 g/m^2	*RR*	**0.013**	**0.007**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**
	iF	**0.005***	**0.005***	**0.005***	**0.005***	**0.005***	**0.013***	**0.005***	**0.005***
Dust Load: 1.0 g/m^2	*RR*	**0.005**	0.059	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**
	iF	**0.005***	**0.005***	0.074*	**0.005***	**0.005***	**0.009***	**0.005***	**0.005***

[1]: The non-parametric differences were considered significant for $P \leq 0.05$ (bold).
*: *P*-values represent negative trend between variables (e.g. *RR* for smaller size fraction is greater than that for larger size fraction).

Table S3: Impact of dust load on average resuspension rate (*RR*) and intake fraction (*iF*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

		Movement Set 1					Movement Set 2				
		1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm	1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm
Dust Load: 0.1 g/m^2 < 1.0 g/m^2	*RR*	0.241	0.445	0.333*	0.646	0.959	0.059	0.169	0.203	0.285	0.285
	iF	0.959	0.333*	0.646*	0.575*	0.575*	0-333	0.646	0.508	0.959	0.169

[1]: The non-parametric differences were considered significant for $P \leq 0.05$ (bold).
*: *P*-values represent negative trend between variables.

Table S4: Impact of movement set on average resuspension rate (*RR*) and intake fraction (*iF*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

		Dust Load: 0.1 g/m^2					Dust Load: 1.0 g/m^2				
		1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm	1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm
Movement Set 1 < Movement Set 2	*RR*	**0.013***	**0.005***	**0.005***	**0.005***	**0.386***	**0.007***	**0.007***	**0.007***	**0.007***	**0.074***
	iF	0.646	0.959	0.799	0.959	0.878*	0.139	0.114	0.169	0.333	0.169

[1]: The non-parametric differences were considered significant for $P \leq 0.05$ (bold).
*: *P*-values represent negative trend between variables.

Table S5: Impact of volunteer body mass on average resuspension rate (*RR*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

		Dust Load: 0.1 g/m^2					Dust Load: 1.0 g/m^2				
		1 to 2 μm	2 to 3 μm	3 to 5 μm	5 to 10 μm	10 to 20 μm	1 to 2 μm	2 to 3 μm	3 to 5 μm	5 to 10 μm	10 to 20 μm
Body Mass 1-5 < Body Mass 6-10[#]	*RR*	0.893	0.686*	0.893*	0.893*	0.893	**0.043***	**0.043***	**0.043***	0.080*	0.345*

[1]: The non-parametric differences were considered significant for *P*≤0.05 (bold).
[#]: Divided 10 volunteers into two groups: lightest 5 and heaviest 5, average between both movement sets.
*: *P*-values represent negative trend between variables.

Table S6: Impact of volunteer body mass index on average resuspension rate (*RR*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

		Dust Load: 0.1 g/m^2					Dust Load: 1.0 g/m^2				
		1 to 2 μm	2 to 3 μm	3 to 5 μm	5 to 10 μm	10 to 20 μm	1 to 2 μm	2 to 3 μm	3 to 5 μm	5 to 10 μm	10 to 20 μm
BMI 1-5 < BMI 6-10[#]	*RR*	0.686*	0.686	0.893	0.686	0.500	**0.043***	0.069*	0.138*	**0.043***	0.080*

[1]: The non-parametric differences were considered significant for *P*≤0.05 (bold).
[#]: Divided 10 volunteers into two groups: lowest 5 BMI and greatest 5 BMI, average between both movement sets.
*: *P*-values represent negative trend between variables.

Table S7: Impact of each individual movement (M1-M5) on average resuspension rate (*RR*), *P*-values from Wilcoxon non-parametric, two-related samples tests[1].

Movement Set 1		Dust Load: 0.1 g/m² 1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm	Dust Load: 1.0 g/m² 1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm
M1 < M2	*RR*	**0.017**	**0.012**	**0.018**	**0.018**	**0.012**	0.063	0.093	0.237	0.398	0.237
M2 < M3	*RR*	**0.028**	**0.043**	0.063	0.091	0.889*	0.066	0.139	0.110	0.139	0.515
M3 < M4	*RR*	0.735	0.735	0.889	0.866	0.917	**0.038***	0.139*	**0.038***	**0.028***	0.051*
M4 < M5	*RR*	0.612*	**0.050***	**0.011***	**0.028***	0.753*	0.161*	0.208*	0.207*	0.263*	0.327
M1 < M3	*RR*	**0.028**	**0.018**	**0.043**	**0.028**	**0.012**	**0.012**	**0.008**	**0.012**	**0.017**	0.107
M1 < M4	*RR*	0.063	0.091	0.176	0.463	0.116	0.063	0.069	0.310	0.735	0.866
M1 < M5	*RR*	**0.028**	0.128	0.345	1*	0.237	0.176	0.327	0.499	0.612	0.237
M2 < M4	*RR*	1	1	0.859	0.889	0.735*	0.779	0.263*	0.123*	0.069*	0.093*
M2 < M5	*RR*	0.575*	0.327*	0.674	0.314*	0.889	0.889	0.779	0.674	0.263*	0.123*
M3 < M5	*RR*	0.866*	0.237*	0.069*	0.093*	1	**0.021***	**0.021***	**0.021***	**0.015**	0.314*

Movement Set 2		Dust Load: 0.1 g/m² 1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm	Dust Load: 1.0 g/m² 1 to 2 µm	2 to 3 µm	3 to 5 µm	5 to 10 µm	10 to 20 µm
M1 < M2	*RR*	**0.028**	0.715	**0.012**	**0.017**	0.051	**0.021**	**0.011**	**0.017**	**0.038**	0.116
M2 < M3	*RR*	0.051	0.074	**0.022**	**0.037**	**0.767***	**0.007**	**0.005**	**0.009**	**0.022**	0.110
M3 < M4	*RR*	0.237*	0.441*	0.484*	0.889	0.600	0.445*	0.575	0.646*	0.878	0.767*
M4 < M5	*RR*	0.735*	1*	0.735*	0.612	0.109*	0.674*	0.779*	0.674*	0.674*	0.263
M1 < M3	*RR*	**0.028**	0.068	**0.012**	**0.012**	**0.017**	**0.008**	**0.008**	**0.012**	**0.008**	**0.018**
M1 < M4	*RR*	0.068	0.593	**0.028**	0.173	**0.046**	**0.008**	**0.008**	**0.012**	**0.008**	**0.018**
M1 < M5	*RR*	0.109	0.109*	0.116	0.173	0.225	**0.018**	**0.018**	**0.028**	**0.018**	**0.028**
M2 < M4	*RR*	0.093	0.374*	0.263	0.575*	0.735	**0.028**	**0.037**	**0.047**	**0.022**	0.069
M2 < M5	*RR*	0.499	1	0.779	0.401	0.600	0.484	0.575	0.401	0.779	0.214
M3 < M5	*RR*	0.116*	0.327*	0.208*	0.161*	0.600	0.161*	0.208*	0.327*	0.263*	0.260*

[1]: The non-parametric differences were considered significant for $P \leq 0.05$ (bold).

*: *P*-values represent negative trend between variables.