Clothing as collector and emitter of airborne inhalable particles

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SUMMARY
It is well documented that clothing serves as a reservoir of airborne particles, including bioaerosols. However, little is known about the role of clothing in transporting potentially harmful particles from one location to another that contribute to inhalation exposures. Here we utilize a well-controlled chamber to quantify the size-dependent clothing release fraction (CRF) in the particle diameter range 0.5-10 µm as a function of four fabric motion intensities and three motion types. A programmable robot reproducibly manipulated a fabric that had been previously loaded with a known quantity of test dust. Our results show that 0.3-3% of deposited particles were subsequently released with fabric motion. The percentage of resuspended particles increased with the vigor of fabric movement and varied with motion type. Particle size substantially influenced the CRF, with larger particles exhibiting higher values. These findings could contribute to understanding how bioaerosols are transmitted and controlled.

KEYWORDS
Inhalation exposure, Bioaerosol, Particulate matter, Personal cloud, Resuspension.

1 INTRODUCTION
Sufficient evidence supports an inference that clothing serves as a transport vector, transferring particulate matter from one space to another. McDonagh and Byrne (2014) demonstrated that a substantial fraction of particles formerly deposited onto a clothing fabric are subsequently dispersed into the air by means of physical movement. Evidence indicates that clothing plays a role in collecting and transferring microbial species into the air, such as Staphylococcus aureus (Hambraeus, 1973), fungal spores (Adams et al., 2015) and allergenic pollen (Zavada et al., 2007). Recent studies suggest that human-associated particle emissions span the dominant size range of indoor airborne bacteria, and that a fraction of total particle emissions from clothing is linked to bioaerosols (Hospodsky et al., 2015). Although these studies indicate that clothing can act as a transport vector for airborne particles, including bioaerosols, evidence remains limited that would quantify the significance of this process with regard to particle size, dynamic behaviour, and consequent inhalation exposures. This study aims to quantify the fractional release of airborne particles deposited onto fabric as a consequence of subsequent fabric motion under conditions that are representative of clothing fabric motions.

2 METHODS
For effective control of particle deposition onto clothing and quantification of subsequent release, we deployed a small-scale, well-controlled and well-mixed chamber (0.52 m^3) with a ventilation rate of 0.48 h^{-1}. To avoid contamination from exogenous sources, the supply air was delivered through a HEPA filter, and the chamber was mildly pressurized. During deposition, a laundered rectangular fabric swatch (0.12 m^2) was laid horizontally on the chamber floor and a known quantity of polydisperse Arizona test dust was injected into the chamber through a consistent 2-s air burst process. After that, particles were allowed to fully settle onto the fabric, yielding a dust loading of about 16 mg/m^2. The contaminated fabric was carefully attached to a programmable robot that performed scripted motions. The robot produced fabric surface vibrations similar to those experienced by human clothing, as verified by 3-axis vibra-

tional accelerometers. Once the low background particle levels had been established, the robot was operated for 1 min, after which the air was monitored for 20 min. Particle concentration was measured with two Grimm aerosol spectrometers that provide size-resolved data for particles at 1-min sampling interval. The clothing release fraction (CRF) is evaluated for each particle size section (17 size sections in the range 0.5-10 µm) as the ratio of the particle mass released normalized by the mass of particles previously deposited on the fabric.

3 RESULTS AND DISCUSSION

The aggregate CRF results in the 0.5-10 µm size range (Table 1) span about an order of magnitude range, from 0.3 to 3%, thus confirming that clothing could serve as mechanism for transferring airborne particles from one location to another. The efficiency of particle transport increased with fabric disturbance vigor. Rubbing the fabric liberated 15% more particles than shaking and 45% more than stretching the fabric. We found that the fraction of deposited particles released increased with particle size (data not shown), suggesting that coarse-mode bioaerosols could also be effectively transported by clothing. Given that humans are recognized sources of airborne fungal and bacterial species (Hospodsky et al., 2015) and that there is a continuous material contribution to inhalation exposure owing to particle shedding from human clothing and skin (Licina et al., 2017), we suspect that particles tracked on clothing could make a meaningful contribution to microbial release indoors and to total bioaerosol exposure. It therefore seems worthwhile to consider whether the human bioaerosol exposure can be suppressed by limiting human-associated bioaerosol transmission through tracking on clothes and subsequent release.

Table 1. Mean ± standard deviation of particle mass (0.5-10 µm) during the deposition and resuspension event; and the resultant clothing resuspension fraction (CRF).

Motion	Intensity	Deposited (mg)	Resuspended (µg)	CRF (%)
Stretch Fabric	Low	1.7 ± 0.1	5.0 ± 1.2	0.3 ± 0.1
Stretch Fabric	Medium	1.7 ± 0.3	11 ± 2.8	0.7 ± 0.1
Stretch Fabric	High	1.8 ± 0.3	24 ± 4.5	1.3 ± 0.2
Stretch Fabric	Vigorous	1.9 ± 0.1	36 ± 6.7	1.9 ± 0.3
Shake Fabric	Vigorous	1.7 ± 0.2	46 ± 4.8	2.6 ± 0.4
Rub Fabric	Vigorous	1.8 ± 0.1	53 ± 3.5	3.0 ± 0.3

4 CONCLUSIONS

Our study suggests that environmental uptake of particles onto clothing fabrics and subsequent release may be an important yet overlooked source mechanism contributing to total airborne particle and bioaerosol burden indoors. Stronger efforts to quantify the role of clothing as a transport vector for bioaerosols in diverse indoor spaces are important for better prediction and control of inhalation exposure, which is ultimately important to human health.

ACKNOWLEDGEMENT

This work was sponsored by a grant from the Alfred P. Sloan Foundation. We thank Randy Maddalena and Veronika Földváry for their assistance in this project.

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