Supporting Information

Review of the Breathability and Filtration Efficiency of Common Household Materials for Face Masks

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Combining measurements of pressure differential and filtration efficiency

There are several terms that have been formulated to indicate the quality of a filter considering both pressure differential and filtration efficiency simultaneously. Two of these indicators are the Quality Factor (Q or QF) [1,2] the filter quality (q) and the Figure of Merit (FOM) which are defined as follows:[2]

$$Q = -\,100 \log \alpha / \Delta P$$
$$q = -\ln \alpha / \Delta P$$
$$FOM = \ln (1-\alpha) / \Delta P$$

where α is penetration (as a proportion) and ΔP is the pressure differential in kPa. Q, q, and FOM should only be compared across materials tested with the same flow velocity and particle size. Q, q, and FOM both assume that the airflow resistance is proportional to the thickness of the filter medium while the penetration decreases exponentially with increasing thickness. If two layers of a filter are used, a new Q, q, and FOM must be calculated for the layered material; Q, q, and FOM are not additive. Additionally, Q, q, and FOM are appropriate only to describe a filter in its initial state, before any particle loading has occurred. Material with a higher Q, q, or FOM value can accomplish a relatively high filtration with a relatively low pressure differential and could be good candidates for face masks.

An alternative indicator is the Filter Utility Factor (FUF),[3] which considers the variation in pressure differential and filtration efficiency as loading increases and is defined as

$$FUF\,(t_F) = \left(\frac{C_0 \cdot \eta_{Fan}}{\Delta p_0 \cdot u_{PE}}\right) \cdot \left[\frac{\int_0^{t_F} [1-P(t)] \cdot dt}{\tau_C + \int_0^{t_F} \frac{\Delta p(t)}{\Delta p_0} \cdot dt}\right]$$

Where
c_0 is the upstream aerosol concentration;
t_F is the filter service life;
Δp_0 is the initial air flow resistance;
u_{PE} is the unit price of energy;
τ_C is the time constant for a filter (each filter has its own time constant function of several parameters);
η is the efficiency of the fan.

Unfortunately, current laboratory methods of dust dispersion do not allow for FUF to be accurately evaluated.[4]

A fourth indicator, K, measures the increase in pressure differential of the filter per gram of dust retained.[4] K is defined as

$$K = \Delta P_{average} / DHC$$

where DHC is the dust holding capacity, which is the amount of dust that can be loaded onto a filter until it reaches a certain final pressure differential (*e.g.* 300 Pa) and $\Delta P_{average}$ is the average pressure differential during the loading phase until the final pressure differential is reached.

Effect of face velocity on pressure differential

As expected, increasing pressure differential is associated with increasing face velocity (Figure S1).[5, 6] However, the increase was not always linear. Note that the pressure differentials in Hao *et al.* 2020 [5] are much higher than all other studies.

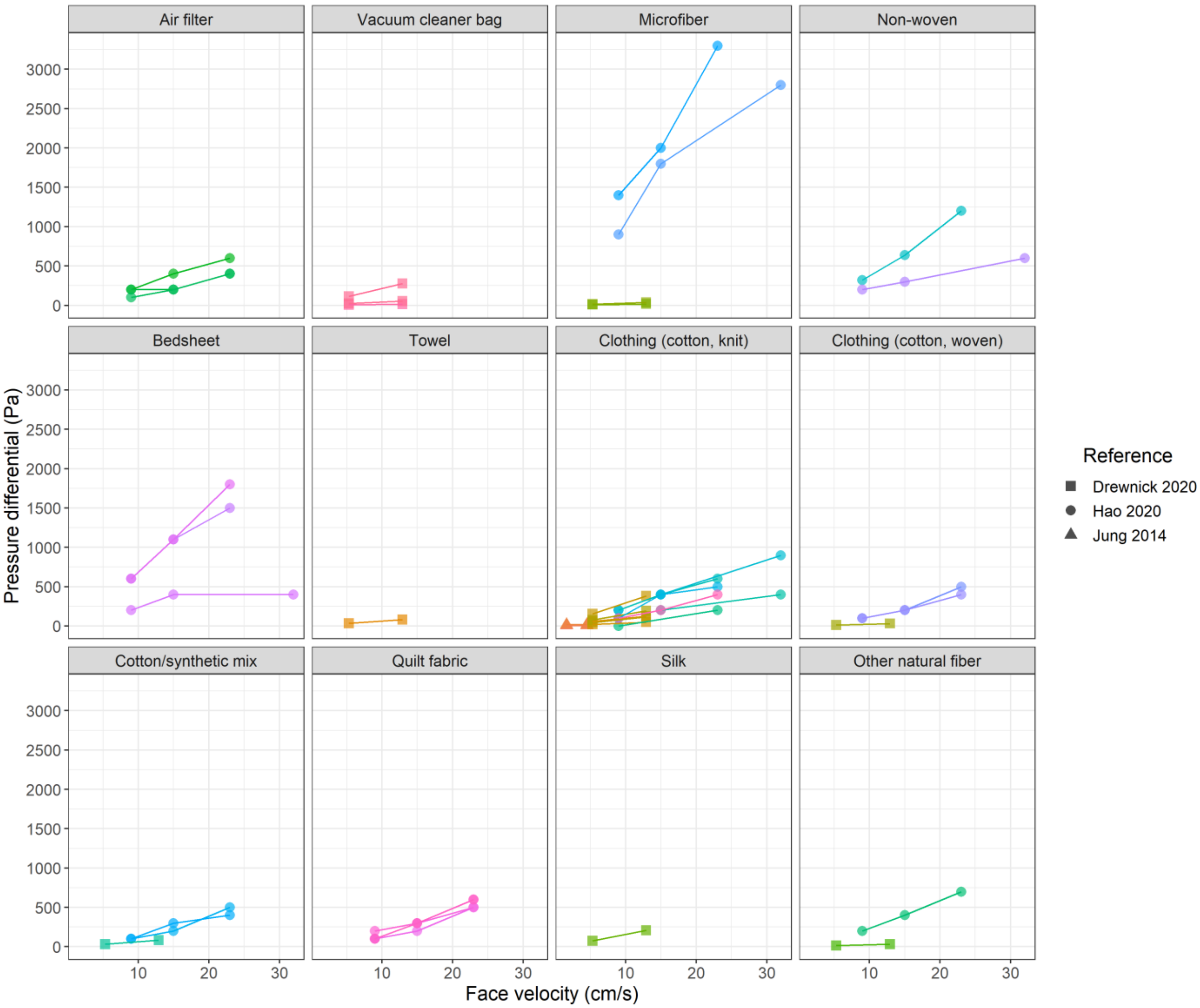

Figure S1. Pressure differential *versus* face velocity for a single layer of various materials.

Effect of layers on pressure differential

In general, there is a monotonic increase in pressure differential with increasing layers of fabric (Figure S2). However, the slope is different between materials and also different for the same material indicating differences in characteristics of a fabric from one region of the same fabric to the next. Some fabrics, such as bedsheets, microfibers, and quilt fabrics have a high pressure differential with just one or two layers, but within microfibers and quilt fabric there is a wide range of differences.

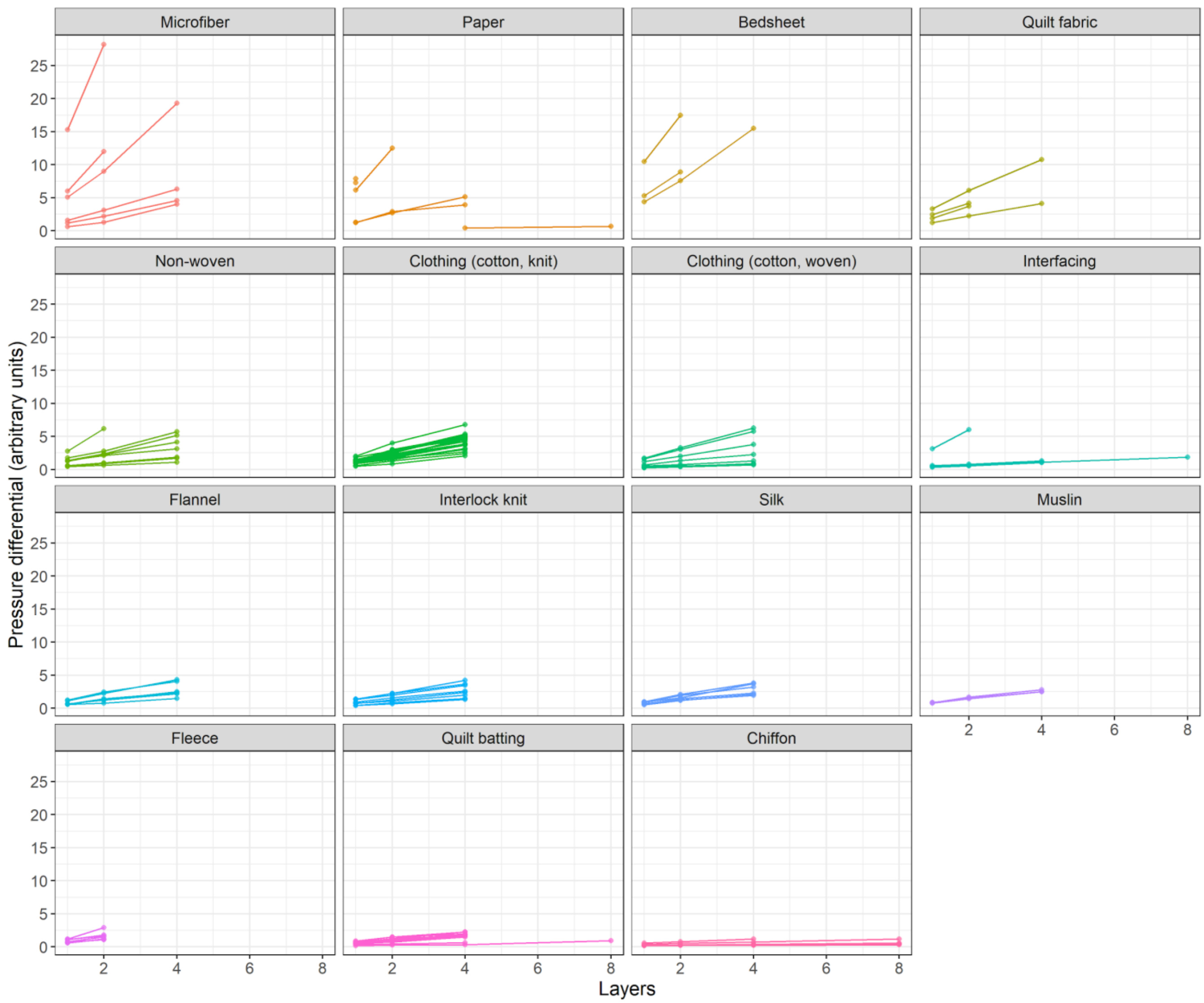

Figure S2. The effect of multiple layers of different fabrics on pressure differential. The horizontal axis is the number of layers of fabric and the vertical axis is the pressure differential.

Detailed summaries of studies that assessed the penetration of bacteria or non-standard particles

Amour *et al.* 2020

In this non-peer-reviewed pre-print,[7] Amour *et al.* tested four cloth masks, one N95 filtering facepiece respirator, and two medical masks that were commercially available in Dar es Salaam, Tanzania. Two types of bacteria, *S. aureus* ATCC 25923 and *E. coli* ATCC 25922, were used to prepare an inoculum that was sprayed at the masks at approximately 31.5 ft^3/min. The unsprayed side of the mask was swabbed at 0 and 4 hr and the samples incubated and counted.

The primary finding of this study was that no mask had an unsprayed surface that was positive for both *S. aureus* and *E. coli* at 0 hr and only one mask, made of cloth, was positive for both when sampled at 4 hr. All positive samples contained only 1 colony-forming unit.

The primary limitation of this study was that the amount of surface area swabbed was not clear and if the surface area varied across masks, those masks with more swabbed surface area would be more likely to be positive for bacteria. While the cloth masks were described as two layers of kitenge fabric with or without a middle filter layer, the characteristics of materials were not presented in enough detail to allow for the experiments to be replicated. This study only qualitatively assessed filtration efficiency so the results are not discussed further in this report. The authors did not assess masks for breathability.

Davies *et al.* 2013

In a peer-reviewed and widely-cited paper, Davies *et al.* [8] tested the filtration efficiency and pressure differential of common household materials and a surgical mask (EN14683 class 1) against penetration by the bacteria *B. atrophaeus* (≈1000 nm in diameter) and the virus Bacteriophage MS2 (≈20 nm in diameter). The fabrics tested included a cotton T-shirt, scarf, a tea towel, a pillowcase, a cotton mix, linen, and silk. Fabric masks were also tested on human volunteers for fit using a TSI PortaCount. Volunteers (N = 21) also coughed into a box with culture media while wearing either a surgical mask, a cloth mask, or no mask.

The primary finding was that the tea towel demonstrated the highest filtration efficiency but also had the highest pressure drop. Increasing from one to two layers of a cotton T-shirt or pillowcase led to little change in filtration efficiency or pressure differential while increasing to two layers of the tea towel increased filtration efficiency and pressure differential. The surgical mask and vacuum cleaner bag had the highest filtration efficiency. The fit test was better with the surgical mask than the homemade mask. Bacterial colony units from the cough test were significantly lower with the surgical and homemade masks than without a mask.

A limitation of this study was that the area of the tested circular coupons was not given, so the face velocity could not be calculated. Consequently, it was unclear how the results compare with results from other studies. Additionally, the pressure measurement technique was not specified and no units were given for pressure, so the breathability of different materials was unclear. Finally, the characteristics of materials were not presented in enough detail to allow for the experiments to be replicated or for consumers to identify/purchase the most effective fabrics/materials. The results cannot be compared to experiments of particles penetrating a mask.

Fischer *et al.* 2020

In this peer-reviewed study, Fischer and colleagues[9] describe and demonstrate a proof-of-principle of an inexpensive method for evaluating the performance of masks at blocking droplets and aerosols released when speaking. In summary, a mask wearer repeated a sentence five times into the path of a laser beam in a dark enclosure. A cell phone camera was used to capture scattering of the laser light due to perturbation by the emitted droplets and aerosols. This low-cost method allowed for comparison of the relative effectiveness of various types of masks at blocking droplets and aerosols emitted during speech. The authors tested this method on synthetic, cotton, fleece, surgical-style and N95 masks, as well as a double-layer bandana. Three masks (surgical-style, one cotton mask option, and bandana) were tested by four different mask wearers each performing 10 trials of the 5-sentence test; the remainder were tested by only one wearer.

The primary finding was that the low-cost method was able to detect differences in how well different masks performed. A fitted N95, surgical-style, and cotton-polypropylene-cotton mask were the top three performing masks. A valved N95 mask performed similarly to several 100% cotton masks. A knitted mask, a double-layer bandana, and a fleece gaiter were the three lowest performing masks. The authors note that more droplets and aerosols penetrated a fleece gaiter than when no mask was used at all and suggest that wearing a fleece gaiter may be counterproductive. However, both the control and fleece gaiter results are from a single person repeating the 5-sentence test 10 times; for both, error bars for relative droplet count were wide and completely overlapped, indicating that there is no significant difference in the results. Wide error bars were also observed with the bandana and knitted mask.

The researchers acknowledged some methodological limitations. Only droplets that pass through the laser beam are counted, potentially undercounting emitted droplets. The resolution of the cell phone camera also limits detection sensitivity and the ability to detect particles below 500 nm. Finally, results may be influenced by face size, speech volume and patterns, and other characteristics unique to the mask wearer. Materials are not described in enough detail for the experiment to be replicated. The results cannot be compared to experiments of standardized particles penetrating a mask.

Parlin *et al.* 2020

In a non-peer-reviewed pre-print, Parlin *et al.*[10] tested natural and unmanipulated silk (cocoon walls of *B. mori* and *H. cecropia*), washed and unwashed 100% mulberry silk, 100% cotton, and polyester, and Chinese surgical mask. The authors examined the hydrophobicity, saturation propensity, gas exchange rate, and penetration of aerosolized water droplets (88 ± 4 cm/s) before and after masks were sterilized with dry heat (70 °C). The authors tested three sources for each material type and three technical replicates for each source. They described the composition and thickness of each material.

The primary findings were that silk-based materials were hydrophobic while cotton, polyester, and paper towels were hydrophilic. Cotton and paper towels had the largest droplet spread. *B. mori* cocoons and cotton had the highest gas exchange rate. A single layer of each material blocked a 2 μL water droplet equally well.

While this study qualitatively suggests that some fabrics are less likely to be penetrated by water than other fabrics, the results cannot be compared to studies that quantitatively examined filtration efficiency because particle filtration efficiency was not assessed. Instead, the study examined the penetration of water droplets. The study also used a face velocity that was nearly ten times higher than the face velocity used in standard methods.

Table S1. Quality assessment of studies that tested the filtration efficiency of bacteria or non-standard particles

Reference	Peer-reviewed	Standard methods used?	Quantitative pressure differential available (Pa)	Quantitative filtration efficiency available	Fabrics described in enough detail so study could be replicated	Number of replicates
[7]	No	Non-standard	No	No	Yes	1
[8]	Yes	Similar to ASTM BFE, but different bacterial sizes	No (no units)	Yes	No	9
[9]	Yes	No	No	No	Yes	10-40
[10]	No	No	No	No	Yes	9

Table S2. Summary of experimental methods of studies that tested the filtration efficiency of bacteria or non-standard particles

Reference	Area under test (cm^2)	Face velocity (cm/s)	Test particle	Particle size	Particle dispersion
[7]	Not specified	Not specified	*S. aureus*, *E. coli*	Not specified	Not specified
[8]	Not specified	Not specified	*B. atrophaeus*, Bacteriophage MS2	95–125 nm, 23 nm	Polydisperse & Monodisperse
[9]	Not specified	Normal talking	Droplets and aerosols naturally formed when talking	Not specified	Polydisperse
[10]	Not specified	88 ± 4 cm/s	Water	Not specified, but volume estimated to be 0.125 ± 0.05 mL of liquid	Polydisperse

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