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Article

Testing filtration capabilities of household fabrics for protection against airborne contaminants

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SUMMARY
Toxic particulates roam the atmosphere in ubiquity, posing a microscopic biohazard to the world. Modern technology like masks reduce viral or pollutant inhalation, but they might be less feasible during health crises due to soaring demands. Common fabrics may serve as alternatives, and in this work, we investigated the most effective household material to serve as a particulate filter among cotton, fleece, wool, and rayon. We hypothesized cotton would occlude more particles than the other fabrics and brands evaluated. The results supported the hypothesis, as among the household fabrics (excluding the commercial and procedural masks which served as controls), cotton exhibited the greatest filtration prowess, slightly surpassing its competitors, whereas rayon demonstrated the poorest filtration. The implications of these findings would be that rayon should be avoided as alternative filters and surfaces like cotton should be opted for instead.

INTRODUCTION
Concerns over worsening air quality has arisen as atmospheric pollution from harmful emissions and transmittable diseases grows (1). Air quality describes the measure of air purity and its conditions, the presence of health-jeopardizing particles, and the assessment of different particulate concentrations in the air (1). Human activity is primarily accountable for influencing air quality as particle emissions far surpass what the atmosphere naturally handles, resulting in irreversible air toxification (2). The people of the world are now constantly susceptible to the harmful effects of the contaminants toxifying the atmosphere, causing widespread damage. Ventilation and other air filtration systems have been developed to counteract this issue and handle particles ranging in diameter above a certain threshold, and with their variable sizes, many particles rarely bypass vents (3). Ranging from nanometers to micrometers in diameter, however, some harmful particles can still bypass these common filters as ultrafine contaminants are small enough to flow through the filters' pores (2).

Most types of ventilation sufficiently occlude viral and dust particles with their integrated, sophisticated technology; however, there are 8.7 million pollution-induced fatalities worldwide every year (4). Densely populated territories contribute to carbon emissions and other forms of air pollution the most. For example, the pollution in China is responsible for 1 million annual deaths (5). Furthermore, vast populations themselves pose a threat to national sanitary welfare, enabling viral particles to roam airborne and overwhelm vents that are incapable of stopping them. Citizens are often confined to wearing masks as portable filtration devices; however, high demands drain this supply and cause cost inflation. Should masks ever be enforced, the mask supply could rapidly deplete, and homemade masks would be an alternative of increasing importance. This experiment investigates the optimal household fabric for this purpose, the results may benefit the fields of air quality and other related domains as they may be expanded upon to reveal finer results. Furthermore, the current database of research on material air filtration provides conflicting evidence. Overall, not many of these kinds of experiments on household filtration have been done; the few that were conducted found different data, and as a result there has been no definitive conclusion as to an optimal material.

Most air filtration systems, masks, and even com fabrics are semi-permeable, being penetrable by fluid substances and even solids if small enough (6). These filters can obstruct various particles but not all since they would otherwise occlude even breathable air as pores smaller than 30 nm impede oxygen flow (7). The pores in a fabric like cotton are smaller than 50 nanometers yet still cannot completely obstruct all particles due to variability in an airstream's force (8). This variance causes some particles to receive the necessary pressure to force through a pore smaller than itself (9). It can also cause incoming particles smaller than a pore to contact a fiber instead of traversing through the pore; thus, cotton can block external matter and allow air to efficiently pass through it without disrupting its flow (10). Notably, in addition to its smaller pore size, pure cotton is thicker than most fabrics; in contrast, wool is also quite thick but has much larger pores (11). That said, the size of the fibers constituting these fabrics vary greatly between each other, and while thin, there are many more fibers in cotton than in wool. Fleece is an intermediary of these two fabrics, neither too porous nor thick; however, its primary ingredient, polyester, has high shape and structure retention, which would result in less variability in fiber and pore sizes (12). Both cotton and rayon contain significant quantities of a compound known as cellulose which has remarkable structural integrity (13). Rayon is often considered an accurate alternative to cotton with a stark difference in softness. Rayon's relatively extreme softness may contradict the integrity provided by its internal cellulose and may facilitate particles passing through it (13). We hypothesized that cotton would act as a better air filter and occlude more particles than the rayon, fleece, and wool fabrics. The implications of the results this investigation would yield could be of practical use to localities with poor ventilation or lack thereof. Ultimately, this experiment aimed to determine

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a convenient way to mimic developed technology.

RESULTS

Using a chamber experiment, we assessed the impact of each fabric, on the measure of $PM_{2.5}$ (μg/m^3) remaining in the air using a controlled experimental setup (**Figure 1**). Cotton's filtration efficacy surpassed the other household fabrics (rayon mean = 49.3 μg/m^3, wool mean = 48.9 μg/m^3, fleece mean = 42.7 μg/m^3), though it did not outperform the experimental comparison group, namely the mask from brand B (mean = 32.8 μg/m^3) (**Figure 2**). Cotton's data support this with the lowest count of remaining particles, (excluding brand B) leaving on average less particles (mean = 41.6 μg/m^3) in the air than the other fabrics yet more than what was observed for brand B's mask (**Table 1**). Its counterpart, the mask from brand A, on the other hand, performed poorly compared to brand B, failing to block many more particles than brand B (mean = 45.1 μg/m^3) (**Table 1**). Fleece filtered similarly to cotton, leaving behind on average just 1.1 μg/m^3 more than cotton; conversely, wool and rayon formed a trend of substantially lesser filtration effectiveness (**Table 1**). The conducted Kruskal-Wallis test revealed a $p<0.001$ value. Through the follow-up Dunnett's post-hoc test, we also saw many statistically significant results aligning with this original analysis. Cotton, fleece, and both masks significantly outperformed the control since every pairwise comparison involving them had extremely high significance ($p<0.001$). Only 6 p-values exceeded the threshold ($p<0.05$), consisting of mainly Brand A where every fabric had insignificantly compared to it. The least statistical significances were noted in the cases of rayon vs. wool ($p=0.99$) and cotton vs. fleece ($p=0.73$). Cotton and fleece yielded high significance when individually compared with rayon or wool. Brand B's comparison with any other material was statistically significant. Taking the adjusted p-value from a follow-up Bonferroni correction into account ($\alpha=0.002$), many of the results considered significant by the original threshold were rendered the opposite, with only six p-values resting below the correction. Four of these six all involved the control variable compared with both masks, fleece, and cotton ($p<0.001$). The other two, involving the brand B mask when compared to wool or rayon, were also below the corrected threshold at $p<0.001$.

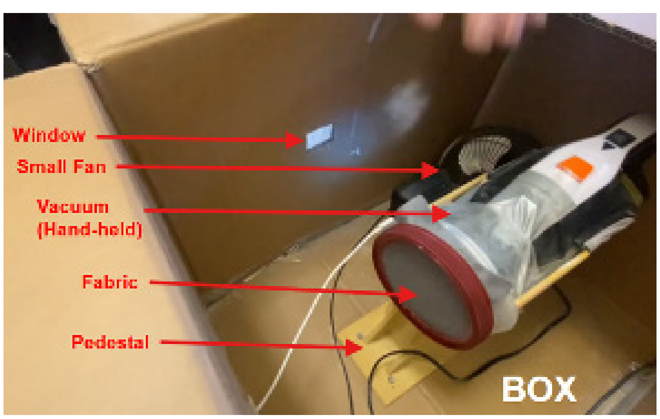

Figure 1: Assembly of acquired materials and experimental setup. The inner contents of the investigation box prior to each trial is shown, including the hand-held vacuum with the square fabric screwed into its mouth and a particle counting device to the side resting on a pedestal.

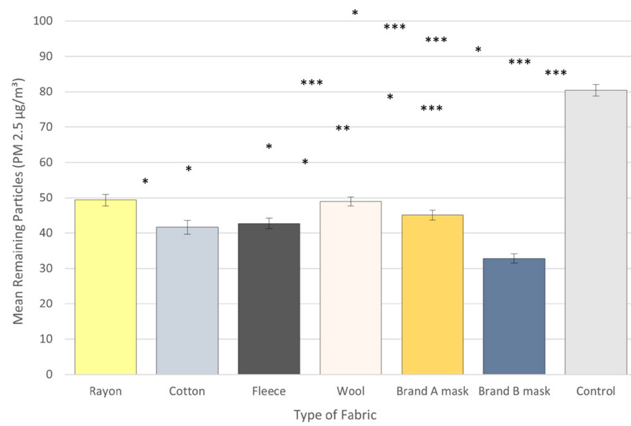

Figure 2. Mean fabric filtration efficacy in the presence of ultrafine $PM_{2.5}$. Chart showing the mean quantity of particles remaining after each trial (n=10). Fabrics and masks filtered 2.46 cm^3 worth of aluminum oxide ultrafine powder. Data are depicted with mean ± standard error shown as error bars. The chart Includes significance values from the Dunn post- hoc test. $P < 0.001$ is shown as ***, $p < 0.01$ is shown as **, and $p < 0.05$ is shown as *.

Accounting for the new threshold, the values which were previously significant as per the original threshold can not be used to reject the null hypothesis and can be considered as examples of variables insignificantly performing against each other.

DISCUSSION

The results showed that cotton possessed the greatest filtration capacity among the household materials, with low detectable particulate concentrations after exposure to it. The p-values of the data also imply that the result of its tests were significant. The most effective household fabric filter, cotton, was not significantly better than its comparison with the control as indicated by its failure to meet the corrected threshold. However, the overall result significance of the experiment as determined in the Kruskal-Wallis test yielded a p-value ($p<0.001$) far below that of even the corrected threshold; thus, the null hypothesis may be rejected. Notably, the two mask brands tested in the experiment produced quite different results, with brand B's prowess far surpassing that of brand A. Despite both being commercialized for public use, this result indicates that while similar, masks from different brands may have differences in filtering efficiencies. Even with identical prices, materials, and other similarities of critical

	Quantity of $PM_{2.5}$ Particles Remaining (μg/m^3)											
	Trial Number											
Fabric	1	2	3	4	5	6	7	8	9	10	Mean	StDev
Rayon	52	53	60	46	48	49	51	41	48	45	49.3	5.21
Cotton	47	28	41	40	42	43	43	37	43	52	41.6	6.26
Fleece	44	43	47	49	44	32	43	38	45	42	42.7	4.76
Wool	48	50	52	50	57	48	48	46	41	49	48.9	4.09
No Fabric	69	83	80	81	81	80	75	83	86	86	80.4	5.13
Brand A Mask	46	44	44	50	52	45	44	45	46	35	45.1	4.46
Brand B Mask	38	33	39	33	31	32	37	26	28	31	32.8	4.21

Table 1. Effect of varied fabrics on the reduction of airborne particulates. Table showing each fabric's filtering prowess (n=10). The process of depositing aluminum oxide powder ($PM_{2.5}$) and cycling it through the filtration setup for 30 seconds was repeated ten times for each variable. The average $PM_{2.5}$ concentrations and standard deviation (StDev) were calculated.

value, masks from different brands can have completely different effects.

Most of our data was consistent with what previous studies and sources described. Considering cotton and fleece's limited pores, it is logical that they most effectively filtered the air around them among the other fabrics. As for the filtration results of wool, while it seems consistent with previous literature that it failed to surpass cotton due to large pores, its thickness may not have been an asset. Since cotton is also thick, it could be concluded that the thickness of a material may have little relevance regarding its filtration efficacy. This is supported by the results that, rayon, which is the thinnest of all fabrics studied here, performed like wool and exhibited a p-value that suggested insignificant differences. Perhaps it is more so a combination of pore size, and properties like structural integrity over thickness that equally contribute to filtration efficacy.

While the other fabrics (rayon, etc.) had not performed as well as cotton or the brand B mask, these fabrics might still have the potential to serve as effective filters. The particles that were deployed into each trial were infinitesimal, even in comparison to the realistic format pollutants, pathogens, or any other harmful particle would come in. It is true that common toxic particulates, like influenza would be too small for most materials to obstruct; however, these all typically reside in minute water droplets in the air which, although still incredibly small, are relatively large (roughly 63 μm) compared to the particles used in the experiment (14). Ultimately, it is extremely likely that the tested fabrics could occlude these microdroplets since all of them have smaller pore sizes.
Previous studies also revealed cotton was a superior fabric in air filtration, supporting the validity of the gathered data (9, 15, 16). The masks were included in this study to serve as a standard, and by comparison, the household fabrics performed relatively well. Both cotton and fleece surpassed a commercial mask (from brand A), yet were completely outperformed by the mask from brand B. While the results of brand B's mask align with several other investigations on its efficacy, brand A's low results also align with its poor performance in other experiments (17).

The experimental results yielding cotton's dominance as a filter support the hypothesis that it would perform with superiority as a filter. However, considering its results yielded that it did not significantly outperform the other materials as its abnormally large p-values suggested. Considering some of the high p-values, sources of error like minor inconsistencies in how each trial was performed could have altered the results to a degree that fleece could have in fact been superior to cotton or rayon; this uncertainty necessitates further study of the investigation for confirmation. Aside from this as a primary source of error, there were potentially a few empirical sources of error in the experimental design and procedure. Alternatively, it could be that any particles remaining in the box after a trial may contaminate subsequent trials. This would likely have been caused by inadequate cleansing of the investigation box, failing to eliminate residue particles.

There are many improvements to counter the sources of error that evinced the experimental design's uncertainty in conclusion. To address the possibility that an inconsistent number of particles being initially deposited interfered with attaining concrete results, more trials should be conducted. To combat inconclusive results because of sources of error, the same resolution of additional trials could be implemented. Finally, improved and more prolonged cleaning efforts could prevent contamination from prior trials. In addition, it would be beneficial if future experiments should incorporate other real-world conditions to create an even more realistic simulation (i.e., including more than one particle type, humidity, and other common air conditions).

This investigation intended to further research on alternative filtration materials, in comparison to widely used filters. The experiment yielded information and results on the efficacies of viable fabrics as readily available substitutes for masks in the event of increased demand for supplies during periods of biohazardous air quality. Overall, the results of this experiment convey that cotton is a viable and effective alternative air filter, outperforming an existing, commercialized product. Individuals should know to avoid using materials like rayon or wool when preparing alternative filters as they do not provide the same, protection as fleece or cotton. Furthermore, considering the commercial masks' results, people should research in-depth the product they choose to purchase to ensure it really is an effective filter. To advance knowledge on this study, research investigating the filtration efficacies among resources that are indigenous to different localities struggling with air quality. The implications of this study could also be furthered by comparative studies exploring how cotton and fleece might perform compared to many more different types of commercial or procedural masks.

MATERIALS AND METHODS

Experimental design

The different independent variables, the tested fabrics, included rayon (Texco, Cat# B0C5ZKFYWQ), wool (Michaels, Cat# 10187345), fleece (Michaels, Cat# D009845S), and cotton (Michaels, Cat# 10594547). Masks from two different brands were included to further compare the results of the investigation to a real-world product. A procedural mask from brand A (Precept, Cat# 42131713) and a commercial mask from brand B (Collectex, Cat# 21944871) were included.

Experimental

A cardboard box (0.7 m^3) functioned as a sealed chamber, with a hand-held vacuum cleaner bearing a particle counting device to its side hoisted onto a pedestal in the center (**Figure 1**). The particle counter (EG, Cat# B078ZS8RVL): instantaneously identified changes in the surrounding air quality, measured in micrograms per cubic meter (μg/m^3). The vacuum device expelled the particles that filtered into it through the fabric via a continuous airstream the device emitted from its back side. This also encouraged particle flow throughout the box, providing air circulation along with a fan in the corner of the box which also blew a small amount of air. The fabrics (10 cm × 10 cm) and masks were secured to the mouth of this vacuum, and the vacuum was used to pull the circulated air in the box through the fabric to be tested. Ten trials were conducted for each fabric, each lasting for a total of approximately five minutes. The constants of the experiment included the amount of aluminum oxide powder averaging 5 μm in diameter per particle (AztroGrit, Cat# B07FPT2CTW) inserted (an amount of particles occupying exactly 2.46 cm^3 of space), the trial duration (30 seconds), and the intensity the internal vacuum operated at. A unit of volume had to be

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used to evaluate the amount of particles deposited because the particles could only be measured in mass per volume by the particle counter when airborne. On one end of the chamber another vacuuming tube was connected to the wall via a closable hole. At the opposite end of this tube's mouth, a flap was cut into the wall to supply the box with air since the vacuum tube would otherwise suck all the air out of the chamber. Particles would journey from circulation and through the filter where it either got trapped or passed through before being ejected from the device to redo the cycle. The number of non-trapped particles in the air was recorded. Since it was unsafe to immediately open the investigation box following a trial and disrupt results, a hole was cut in the side of the box facing the monitor and filled with tape to act as a window to view the particle counter readings.

Data collection

Since the particle counter cannot recognize particles trapped in a filter or pressed against it, the remaining particles after filtration were measured; lower values indicated superior filtration. The initial air quality of the box was recorded before each trial to be deducted from the final measure of air quality at the end of each trial. After each trial, since the particles flowing in the chamber remained airborne and the chamber was unsafe to open, a large vacuum tube was used to cleanse the box connected inside through a hole without having to unseal the chamber.

Statistical analysis

A nonparametric statistical test was opted for to compare how the concentrations of particulates remaining airborne differed following filtration with each fabric. Namely, a Kruskal-Wallis test to was conducted to interpret and assess the data's overall significance. This was opted for over an ANOVA because upon inspection the results were not normally distributed and were positively skewed. There was also a follow-up Dunn's post-hoc test to further yield p-values for each pairwise comparison. Finally, a Bonferroni correction with α = 0.05 was applied to account for the increasing probability of the many variable comparisons falling below the significance threshold. The resulting adjusted threshold, 0.002 (0.05/21), was then implemented as the standard for determining the significance of the Dunn's post-hoc test results.

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