The Effect of Face Mask Orientation on Particle Filtration

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Face masks have been a prevalent topic since COVID-19 appeared, with different forms of face masks becoming popular. Contradictory information on the internet, such as wearing masks inside-out if healthy and wearing masks traditionally if unhealthy, has caused confusion on how to wear masks properly. The purpose of this study was to determine how particle filtration is affected by mask orientation. It was hypothesized that inside-out surgical masks would allow more respiratory particles through than standard-worn surgical masks. It was also hypothesized that gaiter and cotton masks would block the same number of particles when worn traditionally and inside-out. An airbrush passed particles of a red food coloring solution through each side of a mask onto a paper. Then, the percentage of paper covered by particles, which corresponded to the particles not filtered by the mask, was found. A one-way ANOVA ($F(0.0178, 0.0001) = 125.9816$, $p < 0.0001$) found at least one difference between masks and a post-hoc Tukey test found that both methods of wearing surgical masks did not differ from each other, wearing cotton masks traditionally and inside-out did not differ from each other, and that both methods of wearing gaiter masks did not differ from each other. The test results did not support that standard-worn surgical masks would allow fewer respiratory particles through than inside-out surgical masks. It supported that both methods of wearing gaiter masks, as well as both methods of wearing cotton masks, would let the same number of respiratory particles through.

Introduction

The spread of COVID-19 has caused an increase in the usage of masks. Face masks are used to prevent respiratory secretions from transmitting germs and bacteria. A variety of face masks are worn for comfort, breathability, which is how easily the wearer can breathe, design, and more. Types of face masks include surgical masks, KN95 masks, N95 masks, cloth masks, gaiter masks, etc. These masks are all available to the public.

Surgical face masks are made of three polypropylene layers. The inside layer, which is closest to the face and usually white, is typically made of spun-bound polypropylene to absorb respiratory droplets. (Chua et al., 2020). The middle layer's purpose is to block particles from going through either side of the mask. The outer layer is liquid-resistant and used to stop respiratory droplets from reaching the inner layers. Surgical masks have no specific shape. They are shaped around the nose and mouth and wrapped around the ears. Before COVID-19, surgical masks were primarily used in medical settings but are now used by the general public.

Gaiter masks are commonly made of one to two layers of polyester spandex-like material (Fischer, 2020). Recently, the efficacy of gaiter masks has been debated. Scientists have questioned whether gaiter masks are thick enough to block respiratory particles (Lindsley, 2021). Gaiter masks are commonly used because of their breathable fabric and increased comfort. They are worn around the lower half of the face and around the neck. Cotton cloth masks are commonly made of two to three layers of 100% cotton (Horvath, 2020).

Particle filtration is how well a material blocks or stops particles from getting through (Hutten, 2007) and can be measured in multiple ways. A common way of expressing particle filtration is through percentages, where 0% means that no particles were blocked and 100% means that all the particles were blocked. One study measuring particle filtration through different masks used lasers and UV light imaging to visualize particles. Computer programs like Inkscape and ImageJ were used to analyze the particles (Bandiera, 2020). Particle size is often measured in microns. Microns are equivalent to a millionth of a meter.

Recent studies have measured the number of particles that are passed through when wearing a mask and not wearing a mask. Asadi and her colleagues (2020) found that not wearing a mask when breathing had a median of 0.31 particle emissions per second while wearing a KN95 or surgical mask had 0.06 - 0.07 particle emissions per second. Most previous research on the efficiency of face masks have found similar results to Asadi's study. Still, a company named Smart Air Filters tested the filtration of inside-out masks and standard-worn face masks. Smart Air Filters claimed that wearing surgical masks with the white side outwards instead of the blue side outwards can cause a decrease in filtration by 1.7% ("Does Wearing Surgical Masks," 2021). Their experiment used a fan to push air through a surgical mask and measured the particles passing through with a MET-G1 laser particle counter. Other previous research compared the filtration of different types of masks. Whiley et al. (2020) found that surgical masks had a 98.5% - 99.5% filtration rate, while KN95 masks had a filtration rate of 99.3%. Whiley's study was done by releasing particles of bacteriophage MS2 with a nebulizer through face masks and collecting the particles on a Petri dish. The Petri plates were then incubated at 37°C overnight, and the bacterial growth of each dish was compared from each mask.

The purpose of this project was to determine how particle filtration was affected by mask orientation. This experiment measured the difference in particle filtration through inside-out masks and standard-worn masks. Information circulating on the internet convinced people that wearing masks inside-out was for healthy people, and wearing surgical masks the traditional way, with the blue side on the outside, was for sick people (Gray, 2020). Based on this rumor, many people began wearing their masks inside-out. Disproving rumors with this project may also help people realize that not all information on the internet is true. This evidence would hopefully encourage people to wear masks appropriately to ensure the highest particle filtration.

It was hypothesized that wearing a surgical mask inside-out with the blue side on the inside would filter fewer particles than the traditional way of having the blue side on the outside due to the most absorbent layer not being closest to the mouth. If worn inside-out, there is a chance for particles to get through because the particles would not be immediately absorbed. It was also hypothesized that there would not be a difference in filtration of 100% cotton face masks or gaiter masks due to the same material used throughout. An airbrush was used to generate particles with an average size of 0.2mm, which were then passed through the front and back sides of each face mask type for three seconds. Any particles/solution that passed through were collected on paper. The percentage of area the particles took up was found using ImageJ, a computer program used for measuring, analyzing, and saving image data.

Methods

A white sheet of printer paper on a clipboard was placed 3 millimeters away from the mask using a ruler. The airbrush was placed 1 millimeter away from the mask. The mask was held up with two hooks attached to two drawers. The airbrush was filled with a red food dye solution made by mixing 1 mL of food dye and 5 mL of water. The airbrush nozzle released 0.2 mm particles. With the outer side of the surgical mask on the side facing away from the airbrush, the airbrush was sprayed for 3 seconds by holding down the button, and a picture of the paper was taken and put into ImageJ, a computer program commonly used to count and find the area of bacterial colonies. A picture of this setup is included in Figure 1. The picture of the paper was turned into an 8-bit image, and the adjust setting and color threshold were set to automatic. The area of the particles were highlighted in red after changing the adjust and color settings. The percentage of paper covered by particles was found through this equation:

$$\text{\% of Paper Covered by Particles} = \frac{\text{Area of particles}}{\text{Total area of paper}}$$

These procedures were repeated thirty times for each mask type/orientation (see Figure 2) and based on a study conducted by Lucia Bandiera, a bioengineering researcher, and her colleagues. In their study, sodium chloride particles were collected on paper and put into a computer app to count the number of droplets (Bandiera et al., 2020). After data was collected, a one-way ANOVA was conducted followed by a post-hoc Tukey test to find any significant differences between each mask.

Results

The percentages of paper covered by airbrush particles were compared between each mask. The particles passed through the gaiter mask covered the most area followed by the cotton mask, then the surgical mask. The means of the inside-out and standard-worn surgical masks were 0.18% and 0.11%, respectively (see Figure 3). For the cloth masks, the mean of the inside-out mask was 4.54% and the standard-worn mask was 3.96%. The mean of the inside-out gaiter masks was 5.02%, and the mean of the standard-worn gaiter masks was 5.49%. Table 1 shows the mean, range, and standard deviation for each type and orientation of mask.

Figure 4 shows the first and third quartiles with the min and max of each mask in a candlestick chart. The surgical masks had similar ranges to each other. The gaiter masks also had similar ranges to each other. The cotton cloth masks had very different maximums and ranges from each other. The surgical masks were significantly different from the cloth and gaiter masks. The cloth and gaiter masks had similar maximums and minimums.

Using a one-way ANOVA at an alpha level of 0.05 with $F(0.0178, 0.0001) = 125.9816$, $p < 0.0001$ (Table 2). a significant difference was found between at least one mask type or orientation. The null hypothesis was rejected and the alternative hypothesis failed to be rejected. This means that a significant difference was found between one or more mask types or sides.

A post-hoc Tukey-Kramer test (see Table 3) found that wearing a surgical mask inside-out was significantly different from wearing a cloth mask inside-out, wearing a cloth mask traditionally, wearing a gaiter mask inside-out, and wearing a gaiter mask traditionally. Wearing a surgical mask inside-out was found to be significantly different from wearing a cloth mask inside-out, wearing a cloth mask the traditional way, wearing a gaiter mask inside-out, and wearing a gaiter mask the traditional way. Wearing a cloth mask inside-out significantly differed from wearing a gaiter mask the traditional way. Wearing a cloth mask the traditional way differed significantly from wearing a gaiter mask inside-out and traditionally. Wearing a surgical mask inside-out was found to be not significantly different from wearing a surgical mask the traditional way. Wearing a cotton mask inside-out was not found to be significantly different from wearing a cotton mask traditionally. Wearing a cotton mask inside-out was also not significantly different from wearing a gaiter mask inside-out. The last masks without a significant difference between them were the sides of gaiter masks. The results from the Tukey test show that the masks with significant differences have significantly different levels of particle blockage.

Discussion

The purpose of this study was to determine how particle filtration was affected by mask orientation. This study aimed to inform people about the proper way to wear a face mask. By comparing how wearing a face mask inside-out versus the traditional way affects the effectiveness of each mask, the results could be used to inform people of the efficiency of each mask type and side. The different types of masks and their inner and outer sides were compared by their particle filtration efficiency. Surgical masks, cotton cloth masks, and gaiter masks were compared.

It was hypothesized that wearing a surgical mask inside-out would block fewer particles than wearing a surgical mask the traditional way. The other hypothesis was that wearing gaiter and cotton cloth masks inside-out or the traditional way would have no effect on how well each mask blocks particles. Using a one-way ANOVA and a Tukey-Kramer test, the results of this study did not support the hypothesis that wearing a surgical mask inside-out would block fewer particles than wearing a surgical mask traditionally. The hypothesis that wearing gaiter masks and cotton masks inside-out would have no effect on particle filtration was supported. The test also showed no difference between each method of wearing cotton cloth masks. The surgical masks were significantly different from both methods of the cotton and gaiter masks but there was no significant difference between both sides of the surgical mask. The inside-out cotton mask was not significantly different from the inside-out gaiter mask.

Unlike a previous study by SmartAir that found a 1.7% reduction in particles blocked when surgical masks were worn inside-out ("Does Wearing Surgical Masks," 2021), in this current study, the surgical masks were found to have no statistically significant differences between wearing surgical masks inside-out and wearing them traditionally.

Looking at the means, the surgical masks had the most particle blockage (Figure 3). Both sides of the surgical mask were significantly different from the other masks but not significantly different from each other (Table 3). The table of means also showed that cotton cloth masks had the second most particle blockage and that gaiter masks had the third most particle blockage. However, the outside of the cloth mask (simulating the mask worn inside-out) and the outside of the gaiter mask were not significantly different from each other (Table 3). This shows in this study, that wearing a cotton mask inside-out has the same efficiency as wearing a cotton mask the standard way and wearing a gaiter mask inside-out. This also means that wearing a cotton mask the accepted or standard way does not have the same efficiency as wearing a gaiter mask inside-out in this experiment. A study focusing on the efficiency of different types of masks and materials found that surgical masks had a particle filtration efficiency of around 87%. The 100% cotton cloth mask had a filtration efficiency of around 34% for particles at 0.40 microns and the gaiter masks had a filtration rate of 11% (Ayodeji et al., 2022). Ayodeji's study shows that surgical masks are most effective, followed by cloth masks, then gaiter masks. The current study supports Ayodeji's study through surgical masks being the most effective. His study found that cloth masks were

Figure 1 shows the experimental setup. The metal machine is the air compressor used for the airbrush. The hooks are located on the left and right side of the image. The airbrush is located in front of the mask. The two containers in the middle of the image are the 8-ounce weights used to hold the mask down. The paper is located on the clipboard.

Figure 2. *Experimental Design Diagram*

Title of the Experiment*:* The Effect of Face Mask Orientation on Particle Filtration

Hypothesis
The outer side of surgical masks would block fewer particles compared to the front side due to the hydrophobic barriers near the front.
The insides of the cotton reusable face mask and the gaiter mask will block the same amount of particles compared to the outsides due to the same materials throughout the mask.

Independent Variable
Orientation and Type of Mask

Levels of Independent Variable	Standard-worn Surgical Mask	Inside-out Surgical Mask	Standard-worn Gaiter Mask	Inside-out Gaiter Mask	Standard-worn 100% Cotton Mask	Inside-out 100% Cotton Mask
Number of Repeated Trials	30	30	30	30	30	30

Dependent Variable
Percentage of paper covered by particles (%)

Constants
airbrush type, airbrush setting, distance of mask from airbrush, distance of mask from paper, amount of time airbrush is used, brand for each type of mask, type of paper used to see particles, computer app used to count particles, food dye color, food dye brand, concentration of food dye, etc.

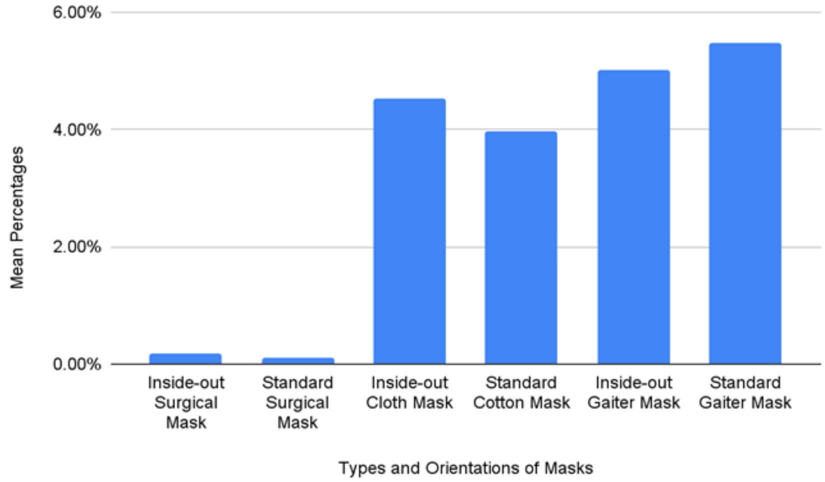

Figure 3. Mean percentages of area covered by particles of each mask orientation and type.

Table 1. *Mean, Range, and Standard Deviation of Each Type and Orientation of Mask*

	Inside-out Surgical Mask (Blue Side)	Standard-worn Surgical Mask (White Side)	Inside-out Cotton Mask	Standard-worn Cotton Mask	Inside-out Gaiter Mask	Standard-worn Gaiter Mask
M	0.18%	0.11%	4.54%	3.96%	5.02%	5.49%
Range	0.73%	0.69%	4.99%	6.35%	4.91%	4.29%
SD	0.002	0.002	0.016	0.016	0.012	0.014

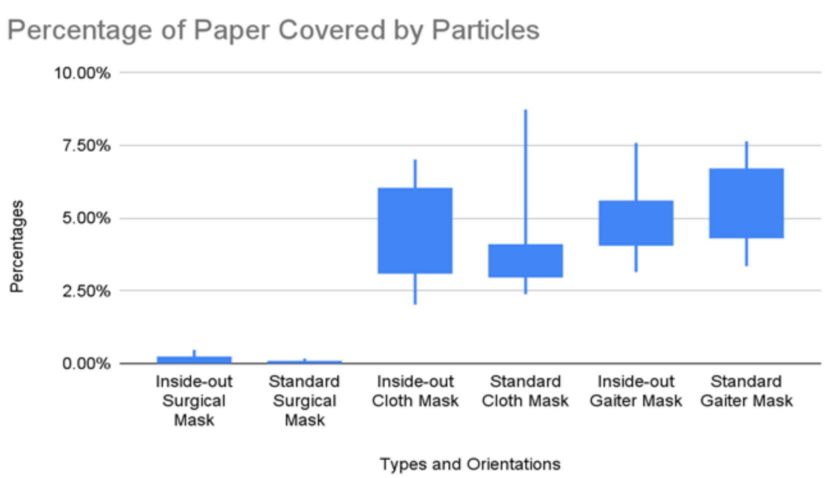

Figure 4. Boxplots for each mask orientation and type . The outliers of 0.69%, 0.73%, 0.30%, 0.40%, 0.47%, 0.70%, 0.43%, and 8.06% were excluded.

Table 2. One-way ANOVA Summary Table (α = 0.05)

Source of Variation	Between Groups	Within Groups	Total
SS	0.0888	0.0245	0.1134
df	5	174	179
MS	0.0178	0.0001	
F	125.9816		
P-value	0.0001		
F crit	2.2661		

Table 3. *Post-Hoc Tukey-Kramer Test*

Pair Comparisons	Absolute Difference Between Pairs	Critical Range	Statistically Significant?
M_1 to M_2	0.0006	0.0089	No
M_1 to M_3	0.0436		Yes
M_1 to M_4	0.0379		Yes
M_1 to M_5	0.0484		Yes
M_1 to M_6	0.0531		Yes
M_2 to M_3	0.0442		Yes
M_2 to M_4	0.0385		Yes
M_2 to M_5	0.0491		Yes
M_2 to M_6	0.0538		Yes
M_3 to M_4	0.0058		No
M_3 to M_5	0.0048		No
M_3 to M_6	0.0095		Yes
M_4 to M_5	0.0106		Yes
M_4 to M_6	0.0153		Yes
M_5 to M_6	0.0047		No

M_1 is the inside-out surgical mask. M_2 is the standard-worn surgical mask. M_3 is the inside-out cotton mask. M_4 is the standard-worn cotton mask. M_5 is the inside-out gaiter mask. M_6 is the standard-worn gaiter mask.

more effective than gaiter masks. Unlike Ayodeji, the present study found that wearing a cloth mask inside-out had the same efficiency as wearing a gaiter mask inside-out.

This unexpected result may have been due to many sources of error. When spraying the airbrush, the airbrush compressor would vibrate and cause the airbrush and table to move. Because of this, the airbrush would occasionally move left or right and spread the food dye to cover more area. Another possible source of error could have been ImageJ detecting the food dye particles on the paper. Occasionally, ImageJ would not highlight clearly visible particles on the paper.

A procedural improvement that could be made is using an extension cord to move the airbrush compressor where it would not be close enough to vibrate the table or airbrush. Another procedural improvement would be to have a phone stand to take pictures of the paper. The pictures were often crooked or blurry and had to be retaken.

Further research should be done to confirm the findings of this study. A replication of this experiment, including the procedural improvements, would help eliminate the major sources of error and reinforce or produce new conclusions. Testing other types of cloth masks other than 100% cotton would provide more insight on the efficiency of cloth masks as a group. It would also be beneficial to test thicker gaiter masks with 3-4 layers and would show the range of filtration they can have.

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Notes and References

Asadi, S., Cappa, C.D., Barreda, S. *et al.* (2020). Efficacy of masks and face coverings in controlling outward aerosol particle emission from expiratory activities. *Scientific Reports* 10**,** 15665. https://doi.org/10.1038/s41598-020-72798-7

Ayodeji, O. J., Hilliard, T. A., & Ramkumar, S. (2022). Particle-size-dependent filtration efficiency, breathability, and flow resistance of face coverings and common household fabrics used for face masks during the covid-19 pandemic. *International Journal of Environmental Research*, *16*(1). https://doi.org/10.1007/s41742-021-00390-6

Bandiera, L., Pavar, G., Pisetta, G., Otomo, S., Mangano, E., Seckl, J. R., Digard, P., Molinari, E., Menolascina, F., & Viola, I. M. (2020). Face coverings and respiratory tract droplet dispersion. *Royal Society Open Science*, *7*(12), 201663. https://doi.org/10.1098/rsos.2016637

Chua, M. H., Cheng, W., Goh, S. S., Kong, J., Li, B., Lim, J. Y. C., Mao, L., Wang, S., Xue, K., Yang, L., Ye, E., Zhang, K., Cheong, W. C. D., Tan, B. H., Li, Z., Tan, B. H., & Loh, X. J. (2020). Face masks in the new covid-19 normal: Materials, testing, and perspectives. *Research*, *2020*, 1-40. https://doi.org/10.34133/2020/7286735

Gray, L. (2021, July 11). *This is why you should never wear your face mask inside out, WHO says*. Best Life. https://bestlifeonline.com/mask-blue-white-side/

Horvath, H. (2020, May 8). *How to buy face masks, according to medical experts*. NBC News. https://www.nbcnews.com/shopping/wellness/how-buy-face-masks-n1199661

Hutten, I. M. (2007). Testing of nonwoven filter media. *Handbook of Nonwoven Filter Media*, 245-290. https://doi.org/10.1016/B978-185617441-1/50021-4

Lindsley, W. G., Blachere, F. M., Law, B. F., Beezhold, D. H., & Noti, J. D.(2021). Efficacy of face masks, neck gaiters and face shields for reducing the expulsion of simulated cough-generated aerosols. *Aerosol Science and Technology*, *55*(4), 449-457. https://doi.org/10.1080/02786826.2020.1862409

Smartair. (2021, July 27). *Does wearing surgical masks with the wrong side out affect their ability to capture viruses?* Smart Air. Retrieved September 2, 2021, from https://smartairfilters.com/en/blog/ does-surgical-mask-orientation-affect-its-ability-capture-viruses/

Whiley, H., Keerthirathne, T. P., Nisar, M. A., White, M. A. F., & Ross, K. E. (2020). Viral filtration efficiency of fabric masks compared with surgical and N95 masks. *Pathogens*, *9*(9), 762. https://doi.org/10.3390/pathogens9090762

Appendix 1

Table A1. *Raw Data of % of Paper Covered by Particles*

Surgical Mask (Outside facing airbrush)	Surgical Mask (Inside facing airbrush)	Cloth Mask (outside facing airbrush)	Cloth Mask (Inside facing airbrush)	Gaiter Mask (Outside facing airbrush)	Gaiter Mask (Inside facing airbrush)
0.03%	0.02%	5.81%	3.62%	4.66%	7.60%
0.19%	0.02%	5.22%	4.10%	4.67%	4.63%
0.05%	0.04%	6.74%	4.87%	8.06%	5.89%
0.01%	0.13%	7.02%	7.18%	6.53%	5.40%
0.03%	0.02%	6.69%	3.75%	3.35%	5.70%
0.05%	0.17%	7.00%	3.35%	5.87%	7.65%
0.04%	0.03%	5.55%	8.74%	5.56%	4.88%
0.23%	0.30%	6.42%	4.23%	6.57%	3.69%
0.45%	0.40%	6.42%	2.85%	5.71%	7.56%
0.01%	0.47%	4.95%	2.94%	5.49%	7.09%
0.02%	0.03%	4.89%	2.84%	5.27%	6.65%
0.18%	0.01%	4.38%	6.95%	4.76%	7.25%
0.02%	0.01%	6.92%	3.63%	4.09%	5.42%
0.01%	0.04%	2.57%	3.09%	5.31%	6.21%
0.15%	0.10%	3.76%	3.48%	4.34%	4.80%
0.16%	0.03%	6.06%	3.52%	6.61%	7.22%
0.08%	0.02%	3.21%	3.95%	3.71%	6.67%
0.23%	0.03%	3.35%	2.38%	3.58%	4.09%
0.06%	0.01%	3.11%	3.35%	4.90%	3.49%
0.69%	0.01%	2.51%	3.09%	3.98%	6.34%
0.02%	0.02%	2.03%	7.65%	4.99%	3.82%
0.41%	0.70%	4.62%	3.23%	4.55%	4.67%
0.09%	0.05%	3.30%	2.93%	4.30%	4.31%
0.02%	0.01%	2.66%	3.22%	7.59%	3.35%
0.18%	0.04%	3.03%	2.85%	4.10%	4.48%
0.19%	0.12%	4.12%	2.74%	3.15%	6.80%
0.06%	0.02%	2.81%	2.98%	5.79%	6.23%
0.73%	0.08%	2.59%	4.40%	3.71%	3.93%
0.47%	0.03%	4.24%	3.54%	4.41%	4.83%
0.44%	0.43%	4.23%	3.42%	5.02%	4.10%