The Efficiency of Different Mask Types at Reducing Airflow

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Abstract

The purpose of enforcing mask-wearing during a global pandemic is to protect others from the wearer by filtering air from the interior to the exterior of the mask. Although surgical masks have been distributed and worn since the beginning of the pandemic, other popular methods of mask wearing have surfaced since, such as wearing fabric masks and stacking surgical masks. However, the efficacy between different mask types is still unclear. By using the distance that a ping pong ball travels from the airflow coming through the different masks, we investigated the efficiency of different mask types at reducing airflow. Human airflow (ex. sneezing, coughing, breathing) was mimicked using a hairdryer since it was difficult to use human subjects during the pandemic. It was hypothesized that if the mask is most effective at reducing airflow from the interior to the exterior of the mask, then it will have the least distance travelled by the ping pong ball. Altogether, it was determined that the surgical masks were least efficient whereas the doubled-up surgical masks were most efficient at reducing airflow, confirmed by non-parametric one-way ANOVA testing (p-value = 3E-14).

Introduction

During this COVID-19 pandemic where masks are mandatory in all (or most) indoor locations, effective mask wearing is key to preventing the spread of respiratory microbes (Ma et al. 1971). There are different types of face masks that can be used, and each has varying capabilities in filtering particles in the air. The most common usage of masks known these days is to protect the wearer, which is to filter air from the exterior of the mask to the interior. However, surgical face masks' original purpose was to protect the people from the wearer by filtering air from the interior of the mask to the exterior (Fischer et al. 1). This shows how crucial masks can be in preventing the spread of not only viruses like COVID-19 that rely on droplet transmission, but also future viruses that may rely on airborne transmission. As such, our group would like to investigate which type of face mask is most effective at preventing or minimizing air flow from the interior to the exterior of the mask.

There has been previous research done to quantify the efficacy of different face masks such as counting droplet transmission using laser beams (Fischer et al. 1) and human study participants (Asadi et al. 2). These methods were difficult for us to apply because one required a big budget for the technology and the other required human interactions which is discouraged during the pandemic. Hence, we had to come up with a new method to quantify the efficacy of different face masks and be able to compare them.

We hope to quantify the effectiveness of the different face masks based on the distance a ping pong ball will travel from the airflow coming through the mask. The less distance the ping pong ball travels, the more effective the mask is at preventing air flow. The ping pong ball will be placed on the exterior side of the mask and a hair dryer will be placed on the interior side of the mask at a set distance. We will mimic the airflow that comes from humans (e.g. sneezing, coughing, talking, breathing) with a hair dryer at high setting. Penetration of particles is increased with increasing flow rate (Tcharkhtchi et al. 114) so we wanted to have high flow rate to test the masks' maximum limits of filtration in the most extreme environments. We tested 3 types of masks: surgical masks (3ply), fabric masks, and double upped surgical masks. We omitted the

N95 masks from this experiment because those are crucial for health care workers and instead we replaced it with the double upped surgical masks.

Methods

In order to create a uniformly level pathway for the ping pong ball to travel smoothly, a cardboard path with 150 cm length was created by placing the main cardboard piece down parallelly to a hardwood floor and lining the sides with the two smaller cardboard pieces perpendicularly to the hardwood floor. The dimensions of the main cardboard piece (10 cm x 150 cm) ensured that the path was wide enough for the ping pong ball to pass vertically, but not too wide that the ball would travel in unnecessary directions, while the height dimensions of the side cardboard pieces (3 cm x 150 cm) ensured that the ball would not be able to jump out of the pathway once airflow was directed. A small cardboard piece (10 cm x 3 cm) was taped securely at the end of the pathway to ensure that 150 cm is the maximum distance that the ping pong ball can travel. The main cardboard piece was then measured by a ruler and a marker was used to mark the piece in 1 cm increments in order for the distance travelled by the ping pong ball to be measured accurately.

In order to measure the control that observed the distance that the ping pong ball will travel without any mask, the ping pong ball was placed onto the beginning of the main cardboard piece at the 0 cm mark, centered in the pathway. The hair dryer was plugged into a nearby outlet and placed horizontally onto the hardwood floor right behind the 0 cm mark with the air outlet facing the ping pong ball, ensuring that the air outlet was facing the middle of the ball at a 0°

angle and straight horizontally to the pathway. The hair dryer was turned on on high power for three seconds using a timer then the distance travelled by the ball was measured using a ruler and recorded in the lab notebook. This process was repeated five times for five trials.

Figure 1. Picture of the start of the cardboard path showing the optimal placement and set up of hair dryer, mask and ping pong ball.

To measure the three other conditions with three different types of masks, the ping pong ball was placed again at the beginning of the main cardboard piece at the 0 cm mark. At the beginning of the cardboard pathway (right behind the 0 cm mark on the pathway), the 3-ply surgical mask was secured perpendicularly to the hardwood floor using masking tape, with the exterior portion of the mask facing the pathway and the interior portion of the mask facing the hair dryer. Enough tape was used to secure the mask in all directions to ensure that the air from the hair dryer would not escape through the bottom or sides of the mask. The hair dryer was placed in the same manner as the control trial, 0 cm away from the mask with the interior of the mask facing the air outlet of the hair dryer directly. The hair dryer was turned on high power for three seconds using a timer, and the distance travelled by the ball was measured using a ruler and recorded in the lab notebook. This process was repeated five times for five trials.

To measure the fabric mask conditions and the double upped mask conditions, the process described in the last paragraph was repeated to obtain five trials of each type of mask. The average distance travelled by each mask was calculated in the lab notebook. Due to the sample size, it is difficult to prove that the population followed a normal distribution. Thus, the Kruskal-Wallis test, a non-parametric one-way ANOVA test was conducted to determine if the data collected was statistically significant, in order to ultimately determine which mask most effectively reduces airflow conduction from the interior of the mask to the exterior environment. In addition, a post hoc test was done afterwards to determine precisely which groups have a significant difference between them, as the Kruskal-Wallis test does not do so, but rather advises if there is a statistically significant difference between one of these groups. The post hoc test we will be using is the Dunn's multiple comparisons test.

Results

We conducted a non-parametric one-way ANOVA test, the Kruskal-Wallis test, with our accumulated data from each group member. We had a total of 5 trials per person for a total of 20 trials. One trial consists of doing one run for each mask type. The one-way ANOVA test was performed using GraphPad Prism 9, using a 95% confidence interval and an alpha of 0.05. The resulting p-value of 3E-14 was extremely low. As the p-value is below our alpha of 0.05, we reject the null hypothesis that there is no significant difference between the means of the groups. This indicates there is a statistically significant difference between the means of fabric, surgical, and doubled-up surgical masks.

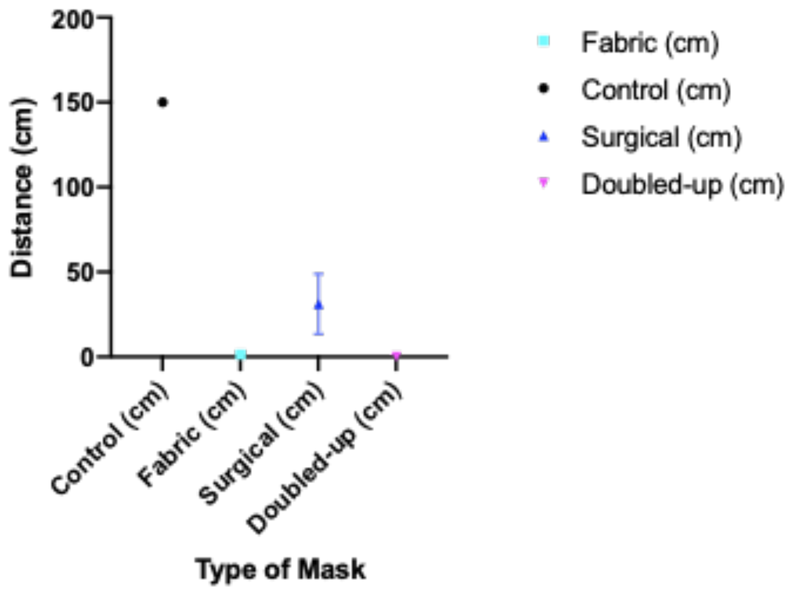

Figure 2. Types of masks plotted against the distance it travelled respectively. Each group has 20 trials averaged out. Error bars are only present for fabric and surgical masks as they were the only groups that had variance.

As seen in Figure 1, the control group (no mask) travelled the furthest with the average distance being 150 cm (maximum distance in experimental set-up). Surgical masks travelled the second furthest with an average distance of 31.275 cm across 20 trials. In comparison, fabric masks had much less distance travelled with the average being 1.375 cm. Lastly, in all trials, the doubled-up masks had 0 cm travelled.

However, as the Kruskal-Wallis one-way ANOVA does not tell us exactly which groups have a significant difference between them, only that a significant difference exists between the groups, we conducted a post hoc test. We utilized Dunn's multiple comparison test as seen below to determine which two groups have a significant difference between them.

Dunn's multiple comparisons test	Mean rank diff.	Significant?	Summary	Adjusted P Value
Control (cm) vs. Fabric (cm)	40.93	Yes	****	<0.0001
Control (cm) vs. Surgical (cm)	22.08	Yes	*	0.0123
Control (cm) vs. Doubled-up (cm)	57.00	Yes	****	<0.0001
Fabric (cm) vs. Surgical (cm)	-18.85	No	ns	0.0508
Fabric (cm) vs. Doubled-up (cm)	16.08	No	ns	0.1484
Surgical (cm) vs. Doubled-up (cm)	34.93	Yes	****	<0.0001

Table 1. Post-hoc Dunn's multiple comparisons test. Summary indicates significance level. ns: not significant | number of in summary column indicates how significant it is with **** being the maximum of "very significant".

As shown in table 1, Dunn's multiple comparison test has determined that the only two groups that do not have a significant difference between them are the fabric masks versus surgical masks, and fabric masks versus doubled-up surgical masks.

Discussion

We found that surgical masks resulted in the largest distance travelled by the ping pong ball and polyester fabric masks resulted in a small distance travelled. Ping pong balls did not travel any distance in any of our trials when placed in front of doubled-up surgical masks. This means that surgical masks allowed the most amount of airflow through and doubled-up surgical masks allowed little to no air through as the ping pong balls did not travel any distance.

Our results support our hypothesis that the face mask most effective in reducing airflow will be the one that allows the ping pong ball to travel the least distance. This experiment was conducted to determine the most effective mask for protection and to reduce transmission of COVID-19. Although airflow does not necessarily correspond to the number of microbes transmitted, it does provide a good understanding of its effectiveness in decreasing microbial transmission through water droplets.

Non-parametric one-way ANOVA testing determined that there is a significant difference in the amount of airflow passing through between the surgical, fabric and double-up masks. It determined a p-value of 3E-14 which is much smaller than the alpha value of 0.05, therefore we can conclude that the means of the three conditions are significantly different. The post-hoc Dunn's multiple comparisons test indicates that the only two groups that do not have a significant difference between them are the fabric masks versus surgical masks, and the fabric masks versus doubled-up surgical masks. This result indicates that there is a negligible difference between using a fabric or surgical mask and a fabric or doubled-up surgical mask to reduce airflow conduction from the interior of the mask to the exterior environment.

Air is composed of primarily oxygen, nitrogen and argon molecules which are 0.299, 0.305 and 0.363nm respectively. Water droplets from day-to-day airflow such as breathing and coughing can range from 0.6μm to 1mm or even larger (Stilianakis et al. 1355). For masks to be considered effective, we must account for its filtration effectiveness and breathability. Due to the material used to construct the masks, surgical masks have smaller pores than fabric masks, but the area of pores in surgical masks are greater than fabric masks (Konda et al. 6344). The material (polypropylene) used to make surgical masks are smaller in diameter than other materials for fabric masks, such as polyester or cotton, in which the diameter is larger which makes the pores are larger as well (Konda et al 6344.). Doubled-up surgical masks would have a higher density of polypropylene than just one surgical mask which explains why we saw little to no airflow. Additionally, surgical masks were found to have a 100% filtration efficiency for molecules 0.5μm in size whereas polyester was at 43% (Rogak et al. 407). Surgical masks which are made of polypropylene can hold strong charges which increases filtration ability (Rogak et al). In terms of its ability to decrease transmission of microbes, surgical masks do contain an inner layer to absorb moisture from the wearer, a middle layer for filtration and an outer layer that repels external moisture, but there is still a lack of evidence to prove its efficiency compared to other materials due to loose fitting around the face (Tcharkhtchi et al. 107). Nonetheless, our experiment deemed surgical masks to be most breathable in that the ping pong ball travelled the furthest mean distance.

However, the results should be interpreted with caution as each individual self-conducted the lab in their own homes, presenting unknown factors and variability to the study. Each person used varying brands of masks, which may have affected the results of the study by increasing variability of the mask's ability to reduce airflow, as one brand of 3-ply surgical masks may be made of a slightly different material or material width than a different brand. Another possible error is that some individuals used brand new masks, whereas others conducted the experiment using used masks. Since used masks may have unnoticeable tears or have worn down from daily wear, more airflow may have been conducted through these used masks, increasing the distance travelled by the ping pong ball.

Further experiments can be conducted to explore the effect of humidity and duration on the masks' effectiveness. If possible, rather than measuring the amount of airflow from the interior to exterior of the mask, measuring the filtration efficiency using microbes will be more functional.

Conclusion

After experimentation with using surgical masks, fabric masks, and double-upped surgical masks to observe the distance travelled by a ping pong ball through these masks, it was determined that the surgical mask conducted the most airflow, the double-upped surgical masks had the second most airflow, and the polyester fabric masks conducted the least airflow. Therefore, it can be concluded that the polyester fabric mask is most effective at reducing airflow from the interior of the mask to the exterior environment. In a future study, it is recommended that the filtration efficiency using microbes is measured rather than airflow, and to measure more mask types than the ones investigated today. It is important to note that any conclusions made in this experiment are limited to these three mask types and that the only variable measured was airflow.

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