

The Comparison of FFP2 NR Respirator Mask, 3-ply-filtered Surgical Mask, and 1-ply-filtered Cloth Mask Regarding Their Protective Abilities Against Airborne Disease-Causing Particles

Research Question:

What is the difference between FFP2 NR respirator mask, 3-ply-filtered surgical mask, and 1-ply-filtered cloth mask regarding their protective abilities (the number of particles which would infiltrate behind the mask) against glitter particles (30 grams) for three blows of glitter particles towards the mask, measured in percentage area of the particles under the area that mask covers?

1: Introduction

People, in daily life, mostly get sick and have a “cold” or have an “upset stomach”. Both situations are most caused by airborne diseases. This type of disease occurs due to different bacteria, viruses, fungi, or other infectious particles. These particles find an opening to enter the body, this opening is most of the time either the mouth or the nose. As these organs are respiratory organs, they intake the air in the environment. If this air contains particles such as bacteria or viruses, then the person intaking these can possibly get sick (*Airborne and Direct Contact Diseases - Disease Surveillance Epidemiology Program - MeCDC; DHHS Maine*).

To prevent these kinds of airborne diseases and be protected against the damaging particles in the environment's air, masks are the most used protective equipment. The masks are basically divided into two different groups: regular masks and respirators. The regular masks usually have a regular fit that cannot be altered among different individuals' faces. Also, the regular masks fit poorly and have different, yet less protective, material compared to the respirator masks. The respirators, on the other hand, allow individuals to uniquely fit the mask to their faces while providing a higher level of protection than a regular mask (Ueki et al.).

Among the two main groups of masks, in this experiment, three different mostly used masks models were chosen and they were analyzed regarding their protective ability against airborne particles (Ueki et al.). The chosen masks have different types and are FFP2 NR respirator mask, 3-ply-filtered surgical mask and 1-ply-filtered cloth mask. Among these masks, the FFP2 NR respirator mask is an example of the respirator mask types. The other 3-ply-filtered surgical mask and 1-ply-filtered cloth mask are examples of the regular mask types.

Today, as pandemic has become the daily reality, masks have become people's closest friends. In a time phase like this, it was rewarding and knowledge-increasing from my perspective to analyze how these masks protect people from airborne particles.

The aim of this study is to see which mask has the highest protective effect against airborne particles by using a modelling approach - the airborne particles that are damaging are mimicked by glitter particles (they are mimicked with glitter because it is practically non-favorable to use bacteria or virus particles for airborne particles as told in the preliminary experiment), and the amount of glitter particles that have passed through the mask represent how much a mask has protective ability.

2: Investigation

2.1: Hypothesis

- Null Hypothesis (H_0): Among FFP2 NR respirator mask, 3-ply-filtered surgical mask and 1-ply-filtered cloth mask, there will be no significant difference regarding their protective abilities against glitter – the number of glitter particles that are able to pass behind the mask when it is on the model face.
- Alternative Hypothesis (H_1): Among FFP2 NR respirator mask, 3-ply-filtered surgical mask and 1-ply-filtered cloth mask, the most protective mask against glitter particles in the air will be FFP2 NR respirator mask and the least protective mask will be the 1-ply-filtered cloth mask.

2.2: Background Knowledge

Masks and Their Structures

Masks are worn because they basically create a barrier between the other environment's air particles and people's noses and mouths. As the mask covers the face's chin to nose part, it prevents damaging air particles such as viruses or bacteria from infiltrating people's noses and mouths. Thus, it can be said that masks create a protective barrier against airborne diseases (Chughtai et al.).

The masks, of course, are not mere fabrics that are put on the face. Different masks have different materials serving for protection. Yet, most of them have micro-nano structures such as cellulose - a compound that has a very strong structure due to its strong hydrogen bonds making it very compact - in their 1-3 layered filters with melt-blown fabrics - fabrics that are synthetically produced from polymers which are created in order to have smaller openings compared to the normal fabric. Due to physical properties such as the ones that are described above, masks have great protection against airborne diseases. Specifically, the masks that are used in this experiment have the below features (Duran et al.):

- FFP2 NR respirator mask: Has three layers of synthetic non-woven materials which are different in thickness; has additive cellulose layers providing further protection; has melt-blown fabric technology strengthening and tightening the mask; strong and hard fit and elasticity for the face.
- 3-ply-filtered surgical mask: Has three layers of synthetic non-woven materials which are different in thickness; a less strong and less hard fit and elasticity for the face.
- 1-ply-filtered cloth mask: Has one layer of cloth material in its layer in a constant thickness; the least strong and least hard fit and elasticity for the face.

Air-Borne Diseases and Medicine

With these abilities, masks are worn due to one simple reason in public health – to prevent the distribution of contagious diseases. As known, the most abundant publicly used source is air as it is taken in and given out for breathing. Therefore, it would be applicable to say that it is the most available medium to have particles from everyone living in the same environment - one person would inhale the air the other exhaled. When this public source named air has so many contributors to its contents, contributors as people inhaling and exhaling it, it has a high possibility to contain these contributors' diseased air, too. When a diseased person exhales into the air, the person inhaling that air would take the disease particles in, too. This is how a disease-causing airborne particle is created and causes disease.

With masks being worn, the particles that have the possibility to be inhaled are blocked. Yet, when they are not blocked, they can cause various problems as there are different diseases that can be caused by different types of particles such as bacteria, viruses, fungi, and so on:

- Measles is one example disease that is caused by airborne particles - viruses. The virus has the ability to remain active in the air and on surfaces for 2 hours. It can be transmitted with air and so with basic inhaling. When the virus is taken in, then it causes its most abundant symptom, rash. Then, runny eyes, fever, and so on occur, which leads to death if not treated ('What Are Airborne Diseases?').
- Tuberculosis (TB) is another example disease that is caused by airborne particles – bacterium. In TB's case, for it to be transmitted, the person should be in close contact with another person – for example, two people should spend a lot of time together in a closed room for hours. TB in a person causes cough, high temperature, fever, fatigue, and so on. It mostly attacks initially the lungs of the person, then it spreads to the body. The bacteria is not very dangerous, yet if it is not treated for a prolonged time, it can create serious health problems ('What Are Airborne Diseases?'; 'Tuberculosis (TB)').
- *Penicillium* is another example of a disease-causing air particle – fungus. It is mostly seen in Asia and Africa, and it is very dangerous when it is coupled with HIV (Human Immunodeficiency Virus) in a person. As HIV patients have an already deteriorated immune system, *Penicillium* fungus easily makes the patient's conditions worse by causing symptoms such as fever, weight loss, problems with breathing, and so on. When the fungus is not treated in people, especially in patients with HIV, it can have problematic and even deadly consequences (Guevara-Suarez et al.; *Talaromycosis (Formerly Penicilliosis) | Fungal Diseases | CDC*; *Penicillium Marneffeii Infection and Recent Advances in the Epidemiology and Molecular Biology Aspects - PMC*).

All in all, air particles such as viruses, bacteria, fungi, and so on can cause diseases when they are exhaled and inhaled within the same shared air. All of these airborne particles infiltrate the human through the nose or mouth and welcome themselves to the respiratory system. Then, they all find appropriate locations in the body to live such as the lungs, liver, throat, and so on. As they get higher in number, the person having them gets worse as they make the person's immune system less effective day by day by tiring the immune system to work a lot, making the immune system produce more than the normal amount of immune cells such as macrophages and antibodies a lot continually causing the system to lose its effectivity due to over-production, and affecting the immune system's metabolic pathways which in return creates problems in the production of necessary cells to fight the diseases.

MATLAB Program

MATLAB is a computer program that is devoted to scientists and engineers for mostly mathematics and statistics-based analysis. Basically, it is used to analyze the raw data that is obtained to get to a more understandable analyzed data. Compared to other programs, it has a much wider software that aids in the production of various different versions of the raw data, making MATLAB the most suitable program to be used in this report.

In the report, MATLAB is used to find the percentage area of the glitter particles on the whole area which the mask covers on the face model. In order for this to be found, a code is written and introduced to the program. The code is more detailed analyzed and explained later on in the report.

2.3: Variables

Independent and Dependent Variables	
Independent Variable: Type of mask - FFP2 NR respirator mask, 3-ply-filtered surgical mask, and 1-ply-filtered cloth mask.	Dependent Variable: The number of particles that were able to get behind the area the mask covers, measured in percentage area. ($\pm 0.01\%$)

Controlled Variables	
The Variable	Reasoning
The size of glitter particles (0.01 mm x 0.01 mm in size)	The size of the glitter particles is kept constant because: – If the sizes were different, then the homogeneity of the model of airborne such as bacteria, viruses, or fungi particles in air would be modeled inaccurately as many bacteria in the air have sizes relatively close to each other. – If the sizes were different, then the glitter particles' course in the air would differ as they would have different masses according to their different sizes which would either make them travel too fast or travel too slow towards the model face wearing a mask which would alter the comparable results because the particles would either pass the mask more or pass the mask less as their sizes differ.
The distance where the glitter particles were blown on the mask-wearing model. (30 cm)	The distance where the glitter particles were blown on the face-model wearing mask is kept constant because if the distance were either shorter or longer, then the amount of glitter particles reaching to the face model wearing a mask would differ from trial to trial - if the distance is were longer, the particles reaching would be less and if the distance is short, the particles reaching would be more comparably - affecting the results and deteriorating the comparability.
The amount of glitter particles blown onto the mask wearing model. (240 grams)	The amount of glitter particles blown onto the face-model wearing mask is kept constant because if the particles were either more or less in different trials, then the amount of glitter particles that passed through the mask would differ, too. Yet, this difference wouldn't be due to the differences in mask types, yet it would be due to the difference in the amount of glitter particles. Thereby, the aim of the study about measuring different mask types' protectivity would fail as the outcomes of the study would be different due to the amount of glitter particles blown.
The area enclosed and covered for every single different mask type in every trial.	The area enclosed and covered with every mask is different. Therefore, every mask model covers up and protects different amounts of area on the model-faces. For the comparability between the masks to be standard, the area that every mask uniquely covers is kept constant between the masks' own trials. Thereby, the area particles were proportioned was the same within between the trials, yet different within between the masks. Thus, the comparability of the masks regarding their protective abilities were ensured and linked to the amount of area that they can protect on the face. Also, the area used in calculating the percentage of glitter particles were kept constant in trials so that the outcomes wouldn't be affected with something that - the amount of the area one type of mask covers on the model-face.
The face model used to put the masks on.	The model-face's type used to put the masks on is kept constant because if the model-face's type changes, then the way the masks fit onto the model-face would differ slightly as they have different strengths and elasticities in their structures which would create differences regarding the number of particles passed through the mask because a different fit on a different model-face would create different openings for the particles to pass.

2.4: Preliminary Experiment

A preliminary experiment was conducted to deduce the needed methodology for the experiment. In the preliminary experiment, instead of glitter particles, bacteria solution was used. Escherichia coli bacteria were grown with agar in petri dishes and were mixed with a water solution. Then, this solution was sprayed onto face-model masks that were wearing masks. A sterile gauze pad was placed behind the face-model's mouth and nose, behind the worn mask. This gauze pad was planned to be taken after the bacteria solution was sprayed and placed on an agar plate directly to grow any bacteria that were able to pass through the mask and get placed on the gauze pad. Yet, this process did not work, and no bacteria grew on the petri dishes which were provided with any bacteria the gauze pads had. This procedure not working may be due to different reasons such as

- bacteria not being able to dissolve in the distilled water, so not getting out from the sprayer while it is sprayed and it sticks to the sides of the sprayer container,
- the bacteria not being able to reach to the mask at the first place or,
- the bacteria dying while being sprayed due to pressure used for spraying.

Due to this inappropriate procedure, the aim of this experiment is tried to be gained by modelling the bacteria sprayed with glitter particles being blown onto the masks. With glitter particles, mimicking of the bacteria became easier as the glitter particles didn't have any problem with being blown towards the model-face wearing a mask, and being measured and calculated with photo analysis and computer program code MATLAB. The program MATLAB is a "programming platform designed specifically for engineers and scientists to analyze and design systems and products that transform our world" (*What Is MATLAB? - MATLAB & Simulink*). In this case, a code was written to the MATLAB program's photo analysis part for it to found how much glitter particle were occupying the whole area the mask covers on the face.

2.5: Assumption

In this experiment, initially, it was thought to use bacteria solution to test the protective abilities of the masks. Yet, after the preliminary experiment, it was seen that the bacteria solution usage for this experiment was not useful as it created no outcomes that can be analyzed. Therefore a "modelling" approach was used. In this modelling approach, instead of the bacteria solution, glitter particles were used and were blown towards the model-face masks as if they were the virus or bacteria particles that are in the air.

The glitter particles were chosen instead of the bacteria or viruses in the air because they both aid in the logistics of the experiment and they resemble the air particles such as viruses or bacteria. In the case of logistics, as glitter is a material which has a very distinct color, it is very easy to be seen in the photos and so it is very easy to apply the MATLAB code to the photos.

3: Procedure

3.1: Apparatus

- 240 grams of glitter (± 0.01)
- 12 x face models
- 3 x FFP2 NR masks
- 3 x 3-ply-filtered surgical masks
- 3 x 1-ply-filtered cloth masks
- 1 x 10 cm plastic cylinder
- 1 x board marker
- 1 x Camera
- 1 x Trash bag
- Droplets of water
- A cut-out piece from a pantyhose
- Double-sided tape,
- Single-sided tape
- MATLAB mathematical analysis program

3.2: Photograph of Set-Up

Photo 1: A cloth mask on a model-face after the glitter particle blowing process.



Photo 2: A FFP2 NR respirator on a model-face before the glitter particle blowing process.



3.3: Methodology

Preparing The Mechanism Used For Blowing Glitter Particles

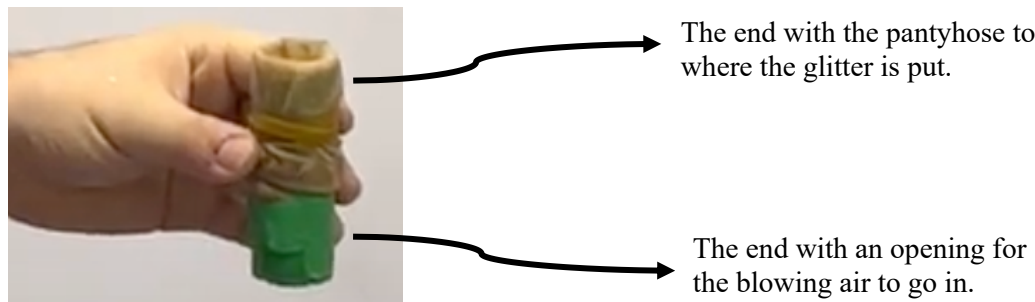


Photo 3: The Mechanism

1. A 10 cm hollow plastic cylinder is prepared from a longer plastic.
2. A 7 cm x 10 cm square piece is cut from a pantyhose.
3. This pantyhose is tightly put around the hollow plastic cylinder's one end with a rubber band - in a way in which one opening of the cylinder becomes covered up with the pantyhose. The other end is left open for blowing the air from that open end. This can be seen in the "Photo 3" above.

The Hollow Plastic Cylinder Preparation: The longer plastic stated was a previously used Vitamin C plastic bottle. It was empty and was not used for any purposes – it was staying unused, so it was recycled and used for this experiment. It was cut to be 10 cm and it was covered with green plastic tape for the brand to be not seen. 10 cm was the decided length because longer than 10 cm would cause hardships in the sense that it would be harder to blow off the air within and expect all the air to meet the pantyhose attached to it. Shorter than 10 cm was not appropriate as the pantyhose would not be able to be attached to it.

Preparing The Model-Faces With Masks



Photo 4: The "Surgical Mask" is prepared in this photo.



Photo 5: The "FFP2 NR Mask" is prepared in this photo.



Photo 6: The "Cloth Mask" is prepared in this photo.



Photo 7: The control group with no mask worn.

Photo 8: An example for the contouring technique's outcome.



1. All 12 of the model-faces are put on different masks - three model faces are equipped with FFP2 NR respirator mask, three model faces are equipped with 3-ply-filtered surgical mask, three model faces are equipped with 1-ply-filtered cloth mask and three model faces are used as control groups with no masks.
2. The masks are tightly placed on the model-faces in an appropriate way, in a way in which the masks close the lower part of the face as a whole, till the nose's middle part.
3. The ear holder parts of the masks are tightly tied from the back of the model-masks.
4. The masks' metal parts placed on the nose part are pushed towards the face for the mask to fit as perfectly as possible to the model-face.
5. A board marker is used to contour the area the masks cover on the model-faces. At the end, this enclosed area is used as the area the glitter particles are calculated in.

Executing The Blowing of The Glitter Particles



Photo 9: The steps 1-7 are demonstrated in this photo for a FFP2 NR respirator.



Photo 10: The step 9 is demonstrated for the 3-ply-filtered surgical mask– the face model is taken and put.



Photo 11: The step 10 and 11 are demonstrated – the 3-ply-filtered surgical mask is taken out and a photo is taken.

1. One of the model-faces with the mask put on is taken and taped onto a wall at a height of approximately 166 cm as it is the average height of a person in world for today (Roser et al.).
2. The part of the floor and wall corresponding to the face-models' below was covered with trash bags for easy cleaning purposes.
3. The mechanism prepared for the blowing-off is taken.
4. The part that is covered and taped with pantyhose on the mechanism is pushed towards the inside, pushed towards the hollow part of the plastic cylinder.
5. 20 grams of glitter powder is put into the pushed-in pantyhose part.
 0. Justification: In a single human cough, there are 3000 droplets and approximately 400 of these droplets are viruses, bacterium, or fungus particles (Wang et al.). If the cough's droplets are assumed to be mostly containing water, and as water's 1 droplet is approximately 0.05 grams ('How Many Molecules Are in a Drop of Water?'), 400 droplets would create 20 grams as when 400 is multiplied by 0.05, it gives off 20. Therefore, 20 grams of glitter is used and put into the pushed-in pantyhose part.
6. The other side of the mechanism is placed right into the experimenters' mouth.
7. The experimenter blows off the glitter powder that is placed in the mechanism towards the face-model wearing a mask from three different perspectives: 90 degrees straight front, 45 degrees right and 45 degrees left, all of which are distanced from the face model by 30 cm.
8. The model-face is taped off from the wall and put on a table very carefully and slowly for no particle of glitter to get away under the mask.
9. The mask that is tightly put on is taken off very carefully for their photographs to be taken.
10. The photos of the face-model without the mask are taken.
11. The process above within between 1-10 is repeated for the other remaining 11 face-models and masks.

The Analysis of The Glitter Particles Which Were Able To Pass Through The Mask

1. The taken photos are put into the MATLAB mathematical analysis program for area calculation.
2. A code was written to calculate the amount of area the glitter particles occupy in the countered region divided by the whole area covered by the counter.
3. Then this area was converted to out of hundred, to a percentage.

The MATLAB code is written below:

```
RGB = imread('aCloth.jpg');
%I = rgb2gray(RGB);
BW = im2bw(RGB,0.5);
[p,q]=size(BW)

B = bwboundaries(BW);
imshow(BW)
%hold on
%visboundaries(B(3))
A = B{2};
mask = poly2mask(A(:,2),A(:,1),p,q);
mask2=~mask;

BW2=mask.*BW;
BW2=or(mask2,BW);
imshow(BW);hold on;
imshow(BW2);

subplot(2,2,1);imshow(RGB)
subplot(2,2,2);imshow(BW);%visboundaries(B(3));
subplot(2,2,3);imshow(mask)
subplot(2,2,4);imshow(BW2);
BW3=~BW2;
Ns=sum(sum(BW3))
perc=Ns/(p*q)*10
```

The code has a basic working mechanism: It initially converts the photograph to RGB (Red-Green-Blue) color codes – the codes used to represent colors. Then, these codes are turned to BW (Black and White) colors according to their strength in color – the strength is represented with the RGB codes, the strength is mostly decided according to the color's darkness. Therefore, it becomes easy to identify the glitter particles on the mask easily as black and the mask as white, as its original color is white and not something dark. After this, the program filters out the areas that are enclosed with black lines. Then, the area that corresponds to the contoured area is filtered and integrated through the program. Then, after this area is filtered, the black areas representing the glitter particles are calculated, integrated, and found as an area. Then, this area is divided by the whole contoured area and converted into a percentage to see what percent of the mask-covered area have glitter particles that were able to pass through the mask.

3.4: Justification

The presented independent variables are used for specific reasons. The three different mask types that are used in the experiment are the most commonly used mask types (CDC). It was thought that as many people in societies use these three types of masks in their daily lives, it would be better to compare their effectiveness. Thereby the experiment would be able to aid in a solution of a daily life problem.

Three repeats were carried out in order to ensure accuracy. As glitter is a very unstable substance and a material to work with, it was quite important to make the 3 repeats because, just like bacteria, glitter has the ability to randomly go ahead and stick on a surface or just pass the surface and do not stick.

The presented dependent variable is chosen because it is the clearest representation of how much of the face that was protected with a mask gets covered in glitter powder. If the measurement was made in glitter amount, then the interpretation of glitter amount would be very hard as the glitter particles are very finely powdered.

3.5: Risk Assessment

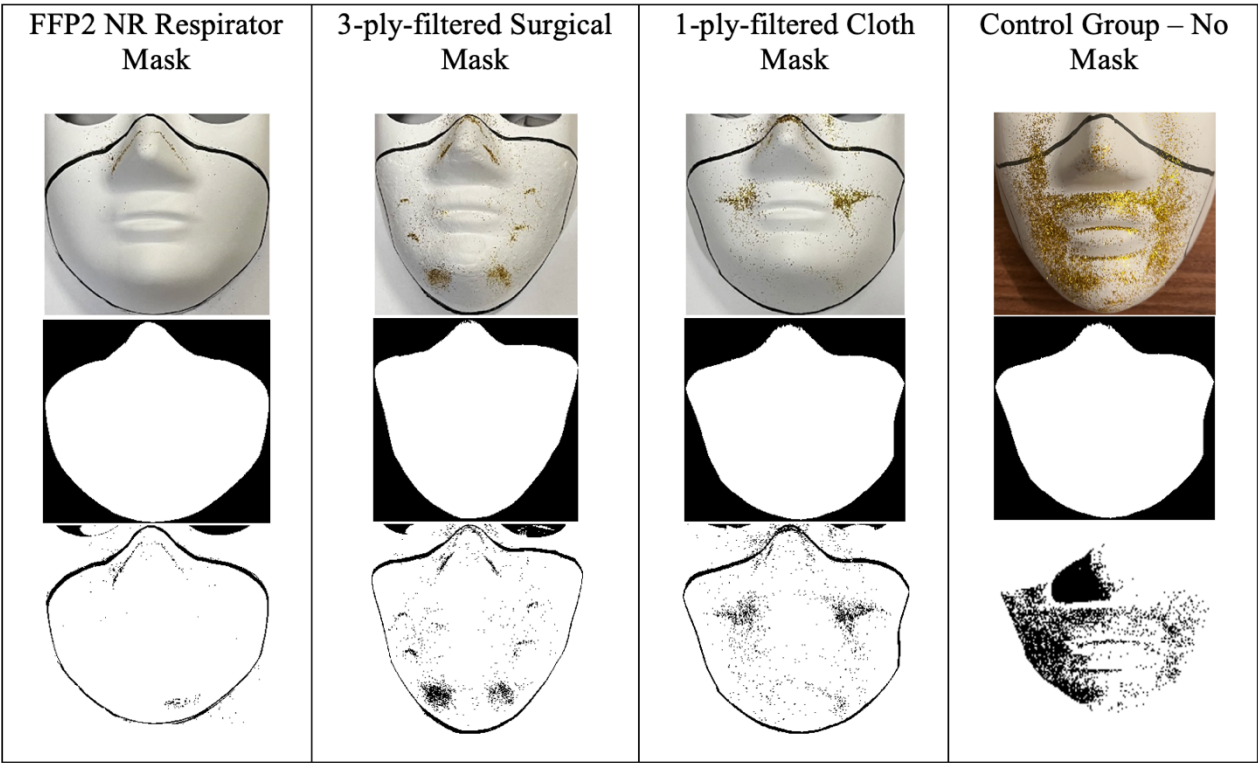
- Safety Issues: Inhalation of glitter damages the lungs and respiratory system (Stieg), especially the respiratory tract. As glitter is divided into very fine particles, it can possibly cut a living tissue in the human body if it is inhaled in large amounts. Therefore, while blowing out the glitter from the built mechanism, small breaks were given between each blowing out so that the experimenter would not have any irritation or build-up of glitter which could possibly affect his inhaling abilities and so respiratory system. Therefore, the safety of the experiment was satisfied.
- Ethical Issues: There were no ethical issues regarding this experiment.
- Environmental Issues: The disposal of glitter and other used particles are the environmental issues that are regarded. In the case of disposing of material used in the preliminary experiment, the Petri dishes and every other material that had contact with bacteria were sprayed with bleach solution. Then, all were left to dry. The used face models and masks that had contact with bacteria were bleached and then disposed of to the red colored hazardous material containing bins in the laboratory which are then disposed of by the Ministry of Education. The materials used in the real experiment were directly taken and put in a garbage bag as they all contain glitter, small particles that are able to be inhaled and create irritation in the lungs. The garbage bag was directly disposed of to a normal bin as it has no hazardous material such as bacteria, viruses, or fungi, or any material or chemical that is hazardous. The glitter that was scattered around the experiment environment was swept up and then the environment was wiped.

4: Data

4.1: Raw Data

Below, the examples for the first trial regarding the raw data are given. The second and third trials' raw data can be found in the "Appendix A" section of the report. All of the raw data are qualitative and not quantitative as they are the data, the photos, that are integrated into the MATLAB program.

In the raw data shown below, the first photograph demonstrates the photo taken after the masks are taken off so that the glitters can be seen. The second photograph shows how MATLAB filters out the area the worn mask on the model face covers as a whole. The third photograph shows how MATLAB filters the glitter particles as dots from the mask covering area it initially deduced in the second photograph.



4.2: Processed Data

Below, are the processed data. These data are the percentage area the glitter particles occupy under the whole area the mask covers the model face. The percentage area in table is found by the following sample calculation – this calculation is already carried out with the code written in the MATLAB, yet below is the demonstration of it:

$$\frac{\text{The area that glitter particles cover within the designated area of the mask coverage on the face}}{\text{Whole area the mask covers on the model face}} \times 100 = \text{Trial Percentages}$$

Data Table #1				
Mask Types	Trial 1 (%) (± 0.01 %)	Trial 2 (%) (± 0.01 %)	Trial 3 (%) (± 0.01 %)	Average (%)
FFP2 NR	0.40	0.89	1.23	0.84
Surgical	2.49	1.93	1.94	2.12
Cloth	4.04	3.23	5.71	4.33
Control (No Mask)	15.3	17.4	18.3	17.0

4.3: Statistical Test

Note: Control group is not integrated into the statistical tests as it does not represent any comparative outcome regarding three different masks’ protective abilities. Yet, it only demonstrates how every mask is effective when compared to an example with no mask. If the control group were to be included to the tests, then it would deteriorate the results as a control group with no mask is not comparable with a variable that includes mask.

To establish a statistical difference and significance between 3 different groups of categorical independent variables and 9 different numerical dependent variables, a one-way ANOVA (analysis of variance) test was conducted as this test is appropriate to see if there is a statistical significance between three different categorical independent variables (*Choosing the Correct Statistical Test in SAS, Stata, SPSS and R*). The test was conducted on Microsoft Excel with an additional software. The test basically demonstrates if there is a correlation between the 3 different mask types.

- Null Hypothesis (H_0): Among FFP2 NR respirator mask, 3-ply-filtered surgical mask and 1-ply-filtered cloth mask, there will be no significant difference regarding their protective abilities against glitter.
- Alternative Hypothesis (H_1): Among FFP2 NR respirator mask, 3-ply-filtered surgical mask and 1-ply-filtered cloth mask, the most protective mask against glitter particles in the air will be FFP2 NR respirator mask and the least protective mask will be the 1-ply-filtered cloth mask.

The results of the one-way ANOVA test can be seen below, in “Data Table #2”.

One-Way ANOVA (Analysis of Variance) - Data Table #2						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	3	2,52	0,84	0,1741		
Row 2	3	6,36	2,12	0,1027		
Row 3	3	12,98	4,32666667	1,59923333		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18,6646222	2	9,33231111	14,9234733	0,00468918	5,14325285
Within Groups	3,75206667	6	0,62534444			
Total	22,4166889	8				

Left, in the test, the “*P-value*” demonstrates the probability level. As the probability level is 0.00468918, a number smaller than 0.05, it can be said that the results are statistically significant. This probability value shows that the null hypothesis is rejected, and there is a convincing evidence that the alternative hypothesis is true.

Yet, as the aim of the experiment is to compare three different mask types and arrange them in their protectiveness abilities, the one-way ANOVA test’s outcomes are not enough as it only shows there is a statistical significance between the outcomes of the

experiment. It does not show which of the two dependent variables are able to demonstrate statistical significance among each other. Therefore, with one-way ANOVA test, the statistical significance can be found, yet a statistical significance that would be acceptable regarding the three masks comparison wouldn’t be gained. Therefore, three different t-tests are conducted, too, to see how every independent variable between each other demonstrate statistical significance.

t-Test: Two-Sample Assuming Unequal Variances FFP2 NR < Surgical		
	Variable 1	Variable 2
Mean	0,84	2,12
Variance	0,1741	0,1027
Observations	3	3
Hypothesized Mean Difference	0	
df	4	
t Stat	-4,2139323	
P(T<=t) one-tail	0,00677167	
t Critical one-tail	2,13184679	
P(T<=t) two-tail	0,01354335	
t Critical two-tail	2,77644511	

Null Hypothesis: There is no difference between the FFP2 NR respirator mask’s and 3-ply-filtered surgical mask’s protective abilities.

Alternate Hypothesis: The FFP2 NR respirator mask is more protective than 3-ply-filtered surgical mask and will have less glitter particles in the area it covers.

Based on the low probability value of 0.00677167 (p is lower than 0.05), the null hypothesis is rejected and hence, there is convincing evidence that the average area that is occupied by glitter particles behind the FFP2 NR mask is lower than the average area that is occupied by the glitter particles behind the surgical mask

t-Test: Two-Sample Assuming Unequal Variances FFP2 NR < Cloth		
	Variable 1	Variable 2
Mean	0,84	4,14
Variance	0,1741	2,3179
Observations	3	3
Hypothesized Mean Difference	0	
df	2	
t Stat	-3,6207667	
P(T<=t) one-tail	0,03426485	
t Critical one-tail	2,91998558	
P(T<=t) two-tail	0,06852971	
t Critical two-tail	4,30265273	

Null Hypothesis: There is no difference between the FFP2 NR respirator mask’s and 1-ply-filtered cloth mask’s protective abilities.

Alternate Hypothesis: The FFP2 NR respirator mask is more protective than 1-ply-filtered cloth mask and will have less glitter particles in the area it covers.

Based on the low probability value of 0.03426485 (p is lower than 0.05), the null hypothesis is rejected and hence, there is convincing evidence that the average area that is occupied by glitter particles behind the FFP2 NR mask is lower than the average area that is occupied by the glitter particles behind the cloth mask.

t-Test: Two-Sample Assuming Unequal Variances Surgical < Cloth		
	Variable 1	Variable 2
Mean	2,12	4,32666667
Variance	0,1027	1,59923333
Observations	3	3
Hypothesized Mean Difference	0	
df	2	
t Stat	-2,9297198	
P(T<=t) one-tail	0,04971612	
t Critical one-tail	2,91998558	
P(T<=t) two-tail	0,09943224	
t Critical two-tail	4,30265273	

Null Hypothesis: There is no difference between the 3-ply-filtered surgical mask’s and 1-ply-filtered cloth mask’s protective abilities.

Alternate Hypothesis: The FFP2 NR respirator mask is more protective than 1-ply-filtered cloth mask and will have less glitter particles in the area it covers.

Based on the low probability value of 0.04971612 ($p < 0.05$), the null hypothesis is rejected and hence, there is convincing evidence that the average area that is occupied by glitter particles behind the surgical mask is lower than the average area that is occupied by the glitter particles behind the cloth mask.

From all the above, t-tests, between all coupling independent variables, there is a statistical significance.

4.4: Uncertainties and Interpretation of Outcome

- Uncertainties: In this report, measured uncertainties are the measured grams for glitter particles as ± 0.01 grams and the uncertainty for MATLAB’s photo analysis section as ± 0.01 %. As these uncertainties are very small, they do not have a

great impact on the outcome. Yet, there are unmeasurable uncertainties such as the amount of glitter that does not reach the mask while the blowing process and the glitter that has fallen down from the model face while the model face is carried and the mask on it is removed. These are possible effects that can alter the percentage glitter amount that is found by MATLAB.

- Interpretation of Outcome: According to the outcomes that are obtained with the “Processed Data” and the statistical tests, it can be seen that all masks are protective against glitter, yet the most protective one is the FFP2 NR respirator mask and the least protective one is 1-ply-filtered cloth mask. With this outcome, the effectiveness of masks against airborne particles is seen and their being useful against viruses, bacteria, and fungi can be interpreted.

5: Evaluation

5.1: Conclusion

As can be seen from the experiment’s results, it can be concluded that the FFP2 NR respirator mask is the most protective mask, and the 1-ply-filtered cloth mask is the least protective mask. Therefore, the null hypothesis stated in section 2.1 is directly rejected. This rejection is directly shown in the processed data table shown in the 4.2 Section, the processed data. As can be deduced from the average protectiveness values, the FFP2 NR respirator mask, with 0,84 average, is the most protective mask because the glitter particle area ratio to the area that the mask protects and covers is the smallest, meaning that the lowest amount of glitter that passed through the FFP2 NR respirator mask. Also, it can be concluded again from the average protectiveness values stated in the processed data table in the 4.2 Section, the least protective mask is 1-ply-filtered cloth mask, with a 4,33 average glitter particle area ratio to the area that the mask protects and covers. Thereby, it can be concluded and again supported with the average glitter particle area ratio to the area that the mask protects and covers that the surgical mask is less protective than the FFP2 NR respiratory mask, yet more protective than the 1-ply-filtered cloth mask.

The conclusions derived from the experiment in the sense of the masks’ protective abilities against glitter, a material mimicking the particles and specifically bacteria in air, can be presented as: “FFP2 NR respiratory mask > surgical mask > cloth mask”. The reasoning behind the FFP2 NR respiratory mask being most protective and the 1-ply-filtered cloth mask being the least protective is:

- FFP2 masks have three layers of synthetic non-woven materials which are in different thicknesses, with additions of filtration layers providing effective protection against particles, yet 1-ply-filtered cloth mask has only 1 layer which is made up of cloth, something that is not as thick as “cloth” (*Comparison of FFP2, KN95, and N95 Filtering Facepiece Respirator Classes*).
- The masks comprise a material that is made up from cellulose - the cellulose is strongly pressed and put into the mask as a layer. As cellulose is a material which has many hydrogen bonds within its structure, it uses its tensile strength in order to not let any particles in the air in. Also, the structure’s very tight bonds create microfibrils which in return aids in the tight structure of the cellulose layer of the mask, making the mask the most protective among the other two masks. Yet, the 1-ply-filtered cloth mask does not have any layer made up of any cellulose or any substance that resembles cellulose (Welle (www.dw.com)).
- The FFP2 NR respiratory masks having 2 electrostatic melt blown filters in their layers aids in their protectiveness against particles in the air. The meltdown fibres are done by a process named melt blowing process. “Melt blowing is a conventional fabrication method of micro- and nanofibers where a polymer melt is extruded through small nozzles surrounded by high speed blowing gas”. The meltblown layer having very nano and microfibers basically strengthens and tightens the fabric, making the particles pass through the material in a much harder way. In the case of 1-ply-filtered cloth mask, the 1 layer is not created with meltblown technique so the microfibers and the strength they provide is not present in the cloth mask (Duran et al.; Ueki et al.; ‘How Does an FFP2 Mask Work?’; CDC).
- The FFP2 NR respiratory mask having the best elasticity and fit on the human face makes it the best protection against the particles in the air, too. As known, all masks have some openings at places such as the opening just below the eyes and next to the nose. These openings are very potent openings which can easily receive air particles and make them infiltrate the area on the face the mask normally covers and protects. By a tighter and more compact fit, FFP2 NR respiratory mask allows less particles to pass through the mask, so better protection is gained. Yet, in the case of 1-ply-filtered cloth mask and 3-ply-filtered surgical mask, as the general physical structures of the masks are completely different from FFP2 NR, the fit and compatibility with a human face is less and creates larger openings compared to FFP2 NRs’ fits. Therefore, both 1-ply-filtered cloth mask and 3-ply-filtered surgical mask have less protective ability against particles in the air as more particles are able to enter through the big openings.(Joshi et al.; *Comparison of FFP2, KN95, and N95 Filtering Facepiece Respirator Classes; Airborne and Direct Contact Diseases - Disease Surveillance Epidemiology Program - MeCDC; DHHS Maine; Hasani et al.; Nast*)

5.2: Strengths

- Intricate calculation of glitter particles: The glitter particles are calculated by a program named MATLAB. This program allows users to write codes of many different functions, and for this experiment, a code was written. The code basically allows MATLAB to find the average glitter particle amount that passed through the mask divided by the whole area of

the mask's enclosed space. In this calculation, MATLAB divides the photograph of the model-face to many pixels, as much as a million pixels, so that it would be able to differentiate the glitter powder and non-glitter powder background easily. Thus, a detailed calculation becomes carried out aiding in a more accurate finding.

- Glitter usage instead of bacteria: This experiment was originally planned to be conducted by bacteria as told in the preliminary experiment. It was thought that bacteria will be placed in a solution and will be sprayed. Yet, due to several reasons told in the preliminary experiment part, and also due to the ethical problems arising from bacteria usage by spraying it and creating a possible bacterial infection chance, the bacteria were not used. Instead, a mimicking agent for bacteria, glitter particles, were used. By the usage of glitter, the problems arising from the bacteria were easily eliminated. Also, a possible ethical problem is prevented by glitter particle usage.
- Modelling the scenario as close to real life as possible: In real life, most of the airborne particles are infecting people through coughing or sneezing. The way that the air particles mimicking glitter particles are blown off resembles coughing or sneezing - with one deep breath taken in, for the blowing off, the breath is given directly to the blowing mechanism for the glitter particles to move.

5.3: Weaknesses

- Glitter usage instead of bacteria: If the experiment were to be done with bacteria solution, it would be much applicable. As a mask is designed for protecting against bacteria, virus, or so on, mimicking the bacteria with glitter, even though creates an advantage in the sense of the application of the experiment, as there is no bacteria used, the real case scenario of how really a protection against "bacteria" is present in different masks becomes unable to be tested. So, the negative part of glitter usage is that it does not have the ability to fully demonstrate what would happen in bacteria's case as they have completely different structures, yet only close sizes. In order to rectify this weakness, a mechanism that has a different sprayer that is able to transmit bacteria and not possibly damage the bacteria by applying pressure and so on, and a suitable bacteria solver liquid can be found and used.
- The velocity of blowing off the glitter: In the experiment's glitter blowing off part, the mechanism that glitter is put in was blown from the other side. This blow, as it was conducted with directly the mouth of the experimenter instead of an air-pushing-machine, did not always have the same effect as the velocity of breathing out can not be set to a level by a human. This had the ability to, in return, affect the results of the glitter amount which passed through the mask because the velocity, if not enough, made some of the glitter particles fall on the floor before they were able to actually reach the model-face and mask. A possible way to rectify this weakness, an air-blower that is strong enough to send the glitter particles towards the model-face wearing a mask, yet slow enough to not make the glitter particles hit the face and not fly to anywhere else.
- The glitter being so small and creating a high possibility of error: As the glitter particles are very small in size, it was very difficult to control them while putting the glitter into the blowing-mechanism. Therefore, the deduced mass of the put glitter slightly changes due to the glitter particles that are lost - the loss of glitter particles is very easy as their sizes and masses as particles are very small and light, respectively. Thus, even a mild wind or a small vibration has the ability to cause the glitter particles to be lost. Thereby, as the amount of the glitter particles blown decreases, the possibility of particles passing through the mask decreases, too.
- The glitter not being sticky to a surface as much as a bacteria do: Normally, bacteria, if it passes through the mask, would be able to stick to the model-face's surface - bacteria has cell appendages which sticks to a surface and adhesion of bacteria to the surface is supported by flagella. Yet, glitter particles do not have these structures, therefore have less ability to stick and stay on the surface if it passes through the mask.

5.4: Extensions

In this experiment, only the number of particles that have passed through the mask are analyzed as they are the particles that are closest to being inhaled. Yet, if the experiment were to be carried out again, calculating the area of glitter particles that are present on the masks' outer surfaces can be carried out because, even though people mostly inhale what is inside the protected part of the mask, they touch to the outer part of the mask with their hands while they take the mask off. After being in contact with a mask's outer part, the human hand becomes the carrier of the disease. Thus, it can be a good extension to calculate the outer surface area.

Another extension can be stated, too: as this experiment is an experiment testing different masks' protectivity against particles that are in the air, it aims to find to what extent different kinds of masks can be protective against particles such as viruses, bacteria, fungi or so on. Yet, as it has many hindrances to work with bacteria, and as it is very difficult to work with viruses and fungi without harming the environment that the experiment is carried out, glitter is chosen as the mimicking device instead of the air particles such as bacteria, virus and fungi. Thus, as this experiment is an experiment carried out with models, it could instead be carried out in a more professional lab with more health precautions in order to use real virus or fungi examples to test the masks' protective abilities.

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7. Appendix

Appendix A

FFP2 NR Respirator Trial 2 and 3 Raw Data	3-ply-filtered Surgical Mask Trial 2 and 3 Raw Data	1-ply-filtered Cloth Mask Trial 2 and 3 Raw Data
		
		
Control Group – No Mask		
Trial 2	Trial 3	
		