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Face Mask Use to Protect Against COVID-19; Importance of Substrate, Fit, and User Tendencies

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Face Mask Use to Protect Against COVID-19; Importance of Substrate, Fit, and User Tendencies

by

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Abstract

In 2019, a novel respiratory illness appeared in China and spread rapidly though the country. It was determined that the SARS–CoV-2 virus was the cause of the COVID-19 pandemic. By the end of 2020, almost every continent was experiencing the effects of COVID-19. The virus caused health officials difficulty in determining its route of transmission. They worked tirelessly to discover it was spread via respiratory droplets. Panicked buyers wiped out protective equipment like medical masks and respirators, regardless of what was needed. Essential employees and first responders were subject to large scale personal protective equipment (PPE) shortages as health organizations strengthened their understanding of COVID-19.

Health organizations published guidelines for the creation of homemade face masks. Filtration efficiency, fit, and user tendencies were all questioned for their effect on the efficacy of a homemade mask. While research regarding mask alternatives is ongoing, it is clear that some characteristics do greatly improve mask effectiveness. Components like a nose clip, double cloth layer, and coffee filter are believed to increase effectiveness of some homemade masks. Ultimately, any facial covering provides a rudimentary barrier for expelled respiratory droplets. This study reviewed face mask filtration efficiencies utilizing material, design characteristics, and user tendencies in the scope of COVID-19. The findings of this study concluded that filtration efficiency of homemade masks is not comparable to respirators. Inadequate mask fit and poor user tendencies lead to an increase in likelihood of COVID-19 transmission.

Chapter 1: Introduction.

COVID-19, the illness caused by the SARS-CoV-2 virus, first appeared in Wuhan, China towards the end of 2019. Not long after, news stories of the death toll and infection rate began to scare neighboring countries. It was only a few short months before the virus spread across international borders, and the world became plagued with the COVID-19 pandemic. The year of 2020 was nothing short of a life changing experience for many people across the globe.

In the United States, almost all citizens were negatively affected by COVID-19. The Center for Disease Control and Prevention (CDC) estimates around 27-million have been infected with the disease (2020c). Of the 27-million, 500,000 people have died because of COVID-19. Unfortunately, COVID-19 cases were not the sole issue of the pandemic. As more cases developed, the CDC and other health agencies determined that COVID-19 was likely spread via respiratory droplets formed when exhaling, coughing and sneezing (CDC, 2020c). This caused panicked buyers to wipe the market and stockpile clean of personal protective equipment (PPE).

Suddenly PPE, like face shields, respirators, and standard surgical masks, was scarce and hoarding of common supplies started. Next was school cancelations and a shift to virtual life. Unfortunately, this caused many people who could not support the virtual lifestyle to become unemployed. Those who remained employed were labeled essential personnel and faced a new wave of occupational safety concerns. Nurses, doctors, and first responders were hit the hardest with shortages of PPE. Since they were the ones directly handling infected personnel, they desperately needed respiratory equipment and other PPE necessary to protect from COVID-19.

The CDC quickly stepped in to develop a template for homemade masks to relieve the demand of respirators. People immediately manufactured homemade face masks and donated them to the essential workforce, only to bring up new concerns regarding the efficacy of nonmedical facemasks. The CDC remained confident that facemasks of all kinds could “flatten the curve” of rising infection numbers, and researchers began to determine which material was best.

1.1 Research Questions.

Based on the current knowledge of COVID-19, this study aims to answer the following three research questions:

1. Do homemade face masks provide filtration efficiencies comparable to well established and regulated respirators?
2. Does poor fit of the face mask significantly decrease its ability to protect from COVID-19 transmission?
3. Do poor user tendencies decrease efficacy of the face mask and increase the likelihood of COVID-19 transmission?

Answering these research questions will provide insight to how effective homemade face masks are compared to respirators during the COVID-19 PPE shortage.

Chapter 2: Literature Review.

When considering the type of face mask that is most appropriate for COVID-19 protection, it should be understood how aerosols behave in the air. It is also important to consider the size and characteristics of the aerosol and in this case, the infectious agent. These factors can determine the region in which an aerosol deposits in the respiratory system. These will also determine the best respirator capable of providing the most appropriate protection. Knowing which respirator is best for situations like COVID-19 could lead to better understanding of the best material to use for an alternative mask in the event of another supply shortage.

2.1 Particle Distribution and Settling.

As data became available regarding COVID-19, the CDC (2020c) determined that the major viral spread was through respiratory droplets. Respiratory droplets are formed during exhalation, talking, coughing, and sneezing. One can be infected indirectly via respiratory droplets or directly from a contaminated person or object. Since the COVID-19 virus is extremely contagious, researchers saw direct person transmission within 6 feet of an infected individual. The use of particle distribution and settling patterns proved to be useful in studying the behavior of respiratory droplets containing the COVID-19 virus.

When a person inhales, they are typically breathing in many different particles varying in diameter and mass. This diameter along with other characteristics of an aerosol will determine how and where it deposits in the respiratory system. For example, smaller particles with a diameter less than 4 um are inhaled deep into the respiratory system. Particles larger than this, are more likely to be removed by respiratory anatomy like nasal hairs. In total, there are five primary depositing mechanisms for material in the lungs: impaction, interception, sedimentation, diffusion, and electrostatic attraction (Plog & Quinlan, 2012).

In *Fundamentals of Industrial Hygiene* edited by Barbara Plog and Patricia Quinlan (2012) the types of particle settling behaviors are explained. It explains that impaction occurs when a larger particle collides with a surface, often due to a change in direction. This occurs in the nasopharyngeal region, the region containing the nose and throat. The airflow in this region is very turbulent allowing large particles to be suspended in the airstream until there is an abrupt change in the direction of flow. They also state that interception is similar to impaction, however the particle is not removed by inertia. Instead it just simply collides with a surface like the lining of the bronchial airways in the thoracic region of the respiratory tract. The diameter of particles most effected by impaction and interception ranges from 10-100 um. Sedimentation also takes place in the thoracic region. Here, airflow slows down and larger particles are able to settle out of the airstream by gravitational forces. This typically effects particles ranging from 1-10 um. Once settled in the thoracic region these particles are removed upwards by the mucociliary escalator, the ciliated lining of the bronchi.

Plog and Quinlan (2012) also explain that beyond the thoracic region is the alveolar region, which consists of the terminal bronchioles and the alveolar sacs. Here, airflow is very slow and particles are removed by diffusion. Diffusion is the randomized movement of particles until they come in contact with the lining of the alveolar sacs. Particles 4 um diameter and less are the primary size able to penetrate this deep into the respiratory system. Electrostatic attraction occurs when charged particles are attracted to surfaces where they are collected.

The COVID-19 virus itself is a very small organism that has a diameter of 0.1 um (Stiepan, 2020). When comparing that to respirable droplets that are less than 10 um in diameter, it is easy to understand how a virus can travel all the way into the alveolar region. Even very small respiratory droplets are able to carry the COVID-19 virus into and out of the lungs. Due to its size and ability to cling to respiratory droplets, it can be passed between people within six feet of an infected individual.

2.2 Types of Respirators and Their Uses.

Knowing the primary mechanisms for settling behaviors when aerosols come in contact with the lungs is incredibly important for effective mask design. The market for respirators is large and contains many different types and variations. However, not all masks are created equal, nor do they filter the same type of materials. The most common type of respirator is classified as “air purifying” due to its ability to remove the contaminant from the environment. Each respirator can be designed to remove contaminants using similar methods as the particle settling previously discussed (Plog & Quinlan, 2012). However, it is not the type of settling or collection that classifies the respirator. Instead, it has to do with the characteristics of the unwanted contaminant. These include whether the aerosol is water based, oil based, or dry. The National Institute for Occupational Safety and Health (NIOSH) is responsible for researching and certifying respirators based on their efficiency and efficacy of use in the United States.

According to Plog and Quinlan (2012), there are nine classes of respirators that are separated into N, R, or P series. The N series, like the classic N95, is best used when there are no oil based aerosols present. They can protect an individual from both a liquid or solid aerosol, as long as it does not contain an oil based compound. N series masks can be reused if they are handled with care, do not show damage, and are not exhibiting increased difficulty to breathe. R series masks are designed to protect against oil based aerosols. However, they are only recommended for the duration of one daily shift. Once the filter is used past an 8-hour shift, it is unknown whether the respirator loses efficiency. P series respirators can be used with both oil based and non-oil based aerosols. They also explain that P series can be extended past a working shift, and even reused like the N series. It should be noted that no mask is able to provide a lifetime of protection during re-use, it is precautionary to reuse N and P series within reason.

The number rating of the respirator like the N95, R99, or P100 is used to express their efficiency of particle collection in terms of percent. For example, Plog and Quinlan (2012) state that the N95 has been tested to show filtration efficiency of 95% of non-oil based aerosols with a diameter 0.3 um and less. Similarly, a P100 respirator has proven filtration of 99.97% of aerosols 0.3 um in diameter. The R99 respirator proves to be 99% efficient for oil based aerosols at 0.3 um diameter and less. For each class of respirator there is a design for 95, 99, and 100% efficiency. NIOSH determines these efficiencies by using a sodium chloride (NaCl) aerosol or dioctyl phthalate in the minimum size range for protection.

The difference between a face mask and a respirator may seem subtle, but a distinction does exist. A respirator has the ability to strictly filter out unwanted particles based on their aerodynamic diameter. Whereas a face mask may have some filtering capability, but its primary purpose is to act as a barrier between a person and the environment. For example, cloth face masks are used to keep exhaled particles from the wearer into the ambient environment. This is the basis behind the CDC’s guidelines to wear face masks in public places. When compared to a respirator like an N95 with guaranteed filtration capabilities, the difference becomes more apparent.

Chapter 3: Methods.

This is a literature based study with data compiled using previously published materials. In order to obtain articles, the University of South Florida's library was used for its database advanced search function. It was specified in the advanced search to include peer reviewed and full-text articles. Articles were selected from various databases using specified key words including: "Coronavirus AND lungs OR face masks", "face masks AND efficiency", "Coronavirus infections AND face masks", "face masks AND efficacy or filtration", "Coronavirus AND masks AND material", "face masks AND material AND filtration", "face masks AND shape AND filtration", and "face masks AND habits". These key words allowed for a thorough database search. Simultaneously, a general web search was conducted using the Google search engine to obtain public information regarding COVID-19.

There were no cut off dates to determine if an article could be used. Instead, the relevance of the article's topic, introduction, and results were consulted and determined to fit one of the three research questions. Each article was paired with the research question in which it best displayed relevance. Articles not relevant to the research questions were discarded from the selection. Similar topics were placed together for comparison. For the general web search, only information relating directly to COVID-19 with a reliable website domain was retained. The governmental websites include the CDC, the World Health Organization (WHO), Johns Hopkins, and Mayo Clinic.

For the first and second research questions, two articles were obtained. The research of each article was summarized and the results were compared to one another. For the third research question, one article was obtained. This was summarized then compared to United States governmental websites that specified good face mask use. The particle behaviors and respirator classifications were combined with the research results to outline the efficacy of homemade face masks to prevent COVID-19 transmission during widespread respirator shortage.

Chapter 4: Results.

4.1 Filtration Efficiencies Given Mask Material.

As the COVID-19 pandemic evolved, the demand for face masks greatly increased as local and federal governments issued facial covering mandates. However, many were faced with the question of which material provides the best protection from COVID-19 during work hours and everyday tasks. To determine the filtration efficiency, typically an aerosol is generated and passed through the material. Then, the concentration before and after the substrate is calculated and used to express percent filtration efficiency. Due to the variability in mask material composition, there is belief that homemade face masks produce a wide range of filtration efficiencies. These efficiencies are beneficial to determining if a face mask is comparable to a regulated respirator.

4.1.1 Hao et al.

This study by Hao et al. (2020) determined the filtration efficiencies of different types of materials. These materials were believed to be the main materials commonly used in homemade face mask designs. The criteria for inspection of mask materials as outlined in this study includes percentage of particles filtered, resistance of flow across the filter to simulate breathability, type of material, weave pattern or thread count, face velocity, and particle size. The materials used in this study were either medical or common household materials. The medical face masks included the N95 and surgical masks, which are non-woven polypropylene. Nonmedical materials include household air filters, vacuum bags, coffee filters, bandanas, scarves, pillow cases, and activated carbon filters.

The methods in Hao et al (2020) explained that each filter material was cut into a 37mm diameter circle and installed into a filter holder. An NaCl solution was generated in a continuous output atomizer which was passed through a dilution chamber and a diffusion dryer. It then flowed through the filter substrate and a particle counter was used to determine a concentration differential before and after the mask. This differential was converted to a percentage to represent the filtration efficiency.

Hao et al. (2020) also explained that all the homemade fabric masks were observed to have less than 60% filtration efficiency. It was also reported that bandana material, even when layered, had much lower efficiency and was deemed insufficient for collecting particles with a 0.3 um diameter. The most promising materials for homemade mask efficiency is a combination of a fibrous filter like a vacuum bag or coffee filter with two layers of fabric. The fabric material in addition to the fibrous filter protects the airway from dislodged fibers. Results of this study can be located in Table-I.

4.1.2 Li et al.

The researchers in Li et al. (2020) examined mask ability to capture nano aerosols sized from 0.006 to 0.2 um diameter. Since the size of the COVID-19 virus has a diameter of 0.1 um, it may be possible for nano aerosols to carry the virus. Most NIOSH rated masks are assessed based on their ability to protect from aerosols that are 0.3 um. This study looked at different household materials and their effectiveness to protect from aerosols smaller than 0.3 um. The point of using household materials was to provide essential workers and the public a way to protect themselves from COVID-19 during extreme mask shortages.

Li et al. (2020), used an NaCl aerosol and a real-time particle counter to determine how much was filtered by the face masks. A flow rate through the mask was used to simulate a velocity close to a human cough. The size ranges of aerosols in the cough cloud were 0.1-0.2 um. The researchers generated the aerosol cloud using a nebulizer and passed it through a diffusion dryer. Then, the aerosol traveled through a radioactive source to eliminate electrostatic charge. A centrifugal fan was used to move air across the substrate. Particle counts were taken upstream and downstream of each mask to assess the particle differential, where the downstream measurement was to serve as the part of the mask with facial contact.

After assessing multiple homemade materials Li et al. (2020) decided to analyze paper towels and tissue paper as homemade face masks. The tissue paper was placed either before or after two layers of paper towels. Rubber bands were used as the ear loops and paper surgical masks were used to compare.

Li et al. (2020) results showed an interesting pattern of filtration efficiency. In the range of 0.1 to 0.125 um, all masks exhibited the lowest filtration efficiency. However, at 0.025 and 0.2 um, these masks showed a higher efficiency. The surgical mask with the tissue only dropped below 90% efficiency in this range. The plain surgical mask and homemade mask (two paper towels and one tissue) only dropped below 80%. The best filtration was seen by combining a medical mask and one layer of tissue paper on the internal side of the mask. The worst efficiency was seen with the use of a single tissue paper. Using two paper towels and one tissue paper internal to the mask showed a better efficiency than a plain medical mask at 0.15 – 0.2 um. It was concluded that one tissue and one paper towel do not provide adequate protection from aerosols in this size range. In contrast, two paper towels and one tissue paper, and a medical mask with tissue paper are able to protect from inhalation and exhalation of these aerosol sizes. These results are summarized in Table-I.

4.1.3 Comparison of Hao et al. and Li et al.

Table-I shows a comparison of Hao et al and Li et al. This table lists the particle size used in each article as well as the material type and the filtration efficiency. The filtration efficiency is described in percent particle capture at the specified particle diameter.

Table 1: Comparison of Mask Material and Filtration Efficiencies.

Study Name	**Particle Size Studied**	**Material Type**	**Filtration Efficiencies (Particle Diameter)**
Hao et al. [1]	0.3 um NaCl	N95 (Polypropylene)	94% (0.3 um)
		Surgical Mask (Polypropylene)	69% (0.3 um)
		1000 Thread Bedsheets	55% (0.3 um)
		600 Thread Bed Sheet	45% (0.3 um)
		400 Thread Bedsheet	20% (0.3 um)
		Cotton Bandanas	7% (0.3 um)
		House Air Filters	58% (0.3 um)
		Coffee Filters	52% (0.3 um)
		Carbon Filters	80% (0.3 um)
Li et al.[2]	0.006 - 0.2 um NaCl	Surgical Mask (Polypropylene)	75% (0.2 um)
		Tissue Paper	35% (0.2 um)
		Two Paper Towels Then Tissue	50% (0.2 um)
		Tissue then Two Paper Towels	75% (0.2 um)
		Tissue and Surgical Mask	85% (0.2 um)

[1]Filtration performance of non-medical materials as candidates for manufacturing facemasks and respirators (Hao, Parasch, Williams, & Li et. Al., 2020).
[2] Homemade Masks with Filtration Efficiency for Nano-Aerosols for Community Mitigation of COVID-19 Pandemic (Li, Fan, Lai, & Lo, 2020).

These articles provided insight to material filtration efficiencies of common household materials and compared them to efficiencies of regulated respirators and well known surgical masks. While these studies test material performance, it should be noted that they do not take the fit of the mask into account. Instead, they strictly analyzed the efficiency of the material. A good filtration efficiency is only part of the efficacy to a well-designed face mask.

While looking at Table-I, it is clear that wearing any mask will provide some protection. However, most medical masks performed better than homemade materials in both particle sizes. One exception to this is the use of a surgical mask with one internal layer of tissue paper. This improved the efficiency significantly in the intended aerosol range. Differences in target size range may be one limitation in comparing these studies. Hao et al. (2020) used only 0.3 um NaCl aerosols, while Li et al. (2020) used up to 0.2 um. Both studies followed regulatory guidelines for testing their facemasks with the use of NaCl aerosol. As seen in Table-I, the N95 and medical mask with one tissue performed the best. However, some homemade mask materials do serve as a reasonable alternative for lesser protection in the event of a large inventory shortage as seen during the COVID-19 pandemic.

4.2 Mask Fit and Design Efficacy.

The CDC (2021a) quickly issued guidelines for the use and creation of facemasks in noncommercial settings to aid in the PPE shortage. These guidelines accentuated the need for a facemask to properly contour the users face. The mask must be placed snug against the skin, especially in the areas of the cheekbones. The nose piece and chin of the mask must also contour the shape of the face to ensure the best seal is being achieved. This includes both ear loop designs and tie-back face masks.

During the creation of the facemask, the CDC (2021b) recommends double or triple layered fabric in the choice of two patterns. The first pattern is a flat, six by ten-inch rectangle that requires the use of a thread and needle to stitch the shape of a face mask together. The second pattern is a no sewing method for creating a mask out of leftover fabric. The CDC walks readers through the process beginning with a single piece of fabric folded on its x-axis twice. It is then inserted through two circular elastic bands, and the ends are folded inward towards the mouth. This mask is then placed on the wearer and the outer layer is spread open simulating a disposable medical mask.

4.2.1 Kolewe et al.

With all the variability in mask design, there is merit to questioning which fit leads to the best performance. Kolewe et al (2020) designed their study to evaluate the size distribution and count of aerosols that escape facemasks. The researchers were able to create a replica human head attached to a nebulizer. The nebulizer created an aerosol cloud with a particle size distribution similar to a human exhale. They used an aerosol with size ranging from 0.3 um to 10 um in diameter, which were passed through the artificial airways at 17 liters per minute (lpm) to assess pressure drop for breathability. A particle counter was used in two scenarios to determine the amount of aerosol that escaped vulnerable areas of each mask. In the first scenario, the researchers used a Plexiglas cube (17 inch by 17 inch). The second scenario took place on a benchtop up to six feet away from the mannequin head. They also recorded the pressure drop across each of the mask material to determine breathability. The masks used in this study include a surgical mask and two N95 masks, one with poor fitting and one sealed to the mannequin head. Also, three hand sewn masks were used to introduce a pipe cleaner nose piece, a basic sewn model, and a coffee filter insert.

According to Kolewe et al. (2020), all masks did show a decrease in particle counts relative to the aerosol distribution of the mannequin without a mask. Particle counts were measured at varying positions including the top, front, bottom, and sides of the mask when attached to the head. Kolewe et al used the count median diameter (CMD) to assess the size ranges of aerosols that escaped the face masks. When compared to the no mask conditions, the CMD of all masks except the sealed N95, shifted to larger sizes greater than 1 um diameter. The plain sewn mask and the sewn mask with the pipe cleaner exhibited larger aerosol counts at 1-3 um at the top compared to the sewn mask with the filter. The CMD at the top of all sewn facemasks was 1.84-2.54 um diameter. The surgical mask had the highest count of aerosol escaping the side positions at 1-3 um, with a CMD of 1.85 um. The loose fitting N95 exhibited the largest aerosol count at 3-5 um at the front position, and both N95 masks were able to significantly decrease the number of aerosols escaping from the top and side positions.

Kolewe et al (2020) also tested in an open-air environment where the particle counter was placed along three distances. Their measurements were taken at one foot, three feet, and six feet from the mannequin head wearing the mask to simulate social distancing. Data showed particle counts 48 times greater than the background particle count when no mask was present. All masks, except the tight fitting N95, contributed to elevated particle count at one, three, and six feet when comparing to baseline levels. They ultimately determined that all masks had areas of vulnerability in which particles were able to escape. It was observed that face mask fit influenced the behavior of particle transmission in conjunction with material shape. Having gaps along the sides of the face mask reduce the effectiveness of the mask by allowing particle redirection around the material. While nose clips of homemade masks, like the pipe cleaner, were shown to improve particle capture, their ability is limited as seen by the surgical mask. These results are summarized in Table-II.

4.2.2 Sanchez.

A similar study by Sanchez (2010) was conducted to determine the effects on filtration when a seal was added to standard surgical masks. It is known that masks sealing to the face provide better filtration as opposed to masks with gaps near the nose and cheeks. For this study six masks total were used: three unsealed and three sealed variations. Three particle sizes, 0.5 um, 1.0 um, and 2.0 um, were used to determine how well a seal can improve filtration efficiency. The aerosol consisted of polystyrene latex beads that were generated in a nebulizer. These beads were passed through a diffusion dryer and a radioactive source to deplete electrostatic charge. Then, they were passed through a manikin head which was fitted with the masks. The efficiency was determined by calculating the particle differential on both sides of the mask. The flow rate of the aerosol out of the manikin head was 85 lpm, which the researcher identified as a specific testing parameter by NIOSH used to certify mask filtration efficiencies.

Sanchez's (2010) results showed that sealed masks overall provided better filtration efficiency of 0.5, 1.0, and 2.0 um beads. The mask variation with the worst efficiency was one with no seal where the top mask tie was on the head and the bottom tie was around the neck. This allowed the mask to create large gaps around the face. The efficiencies of this mask were less than 10% for 0.5 um beads, 50% for 1.0 um beads, and >60% for 2.0 um beads. For unsealed masks with crossed ties, the filtration efficiencies at each bead size were significantly higher. At 0.5 um filtration was 20-40%, 1.0 um it was 70-75%, and at 2.0 um it was 70-80%. For the sealed masks, the efficiencies were over 60% for 1.0 and 2.0 um beads. At 0.5 um beads, the efficiency was around 40-50%.

Sanchez (2010) observed that sealed masks were significantly better at capturing aerosols than unsealed masks. However, the size of the aerosol beads greatly influenced the filtration efficiency of both sealed and unsealed masks. Even though the sealed mask performed better overall, it had much lower efficiency for beads less than 0.5 um. The efficiencies at 1.0 and 2.0 um sizes were not drastically different from one another for both sealed and unsealed masks. Sanchez determined that sealed facemasks are the most appropriate for reducing transmission of aerosols. Unsealed facemasks allow a larger number of aerosols to escape through gaps produced by poor fit. These results are summarized in Table-II.

4.2.3 Comparison of Kolewe et al. and Sanchez.

Table-II shows a comparison of the vulnerable areas determined in Kolewe et al (2020) and Sanchez (2010). It shows the study name, size distribution of the aerosol used, and the mask type. For each mask type, the vulnerable areas are identified as either the top, front, bottom and sides of the face mask. The top refers to the area of the nose, and the front is the area directly covering the mouth.

Table 2 – Comparison of Vulnerable Areas and Mask Type.

Study Name	Size Distribution	Mask Type	Vulnerable Areas
Kolewe et al.[1]	0.3-10 um	Loose N95	Top & Front
		Tight N95	Top
		Surgical mask	Sides
		Sewn Fabric	Top
		Fabric/Pipe Cleaner	Top
		Fabric/coffee filter	Top
Sanchez [2]	0.5, 1.0, 2.0 um	Unsealed Surgical Mask	Top, sides, & bottom
		Sealed Surgical Mask	none

[1]Check the Gap: Facemask Performance and Exhaled Distributions Around the Wearer (Kolewe, Stillman, Woodward & Fromen, 2020).
[2]Filtration Efficiency of Surgical Masks (Sanchez, 2010).

These research articles reported how fit was associated with the efficacy of facemasks. Both articles used a replica human manikin head and common face masks. One major difference between Kolewe et al. and Sanchez, is the flow rate of the aerosol across the face mask, with Sanchez's flow being much faster. The Kolewe et al. included a slightly smaller aerosol diameter, but the vulnerabilities were ultimately the same.

Kolewe et al. (2020) used homemade masks in addition to the N95 and surgical masks, and Sanchez (2010) used strictly surgical masks with added variations. Both observed that sealed masks provided the best fit and resulted in higher filtration efficiency. However, as seen in Table-II, nearly all masks had vulnerabilities. The sealed mask in the Sanchez article does not have vulnerabilities because it was artificially sealed to the manikin (2010). The loose fitting surgical masks in both studies were determined to have the worst performance for aerosol transmission reduction. The silicone glue, while important to create a good seal, would not be used on real humans. Data from the silicone sealed mask may not fully represent the vulnerabilities of a mask on a real human head.

Also, bias may occur with loose fitting N95 in Kolewe et al (2020). This mask had a built-in vent on the front position of the mask allowing aerosol to flow outwards with little to no filtration. The use of multiple materials instead of just one type of surgical mask benefits the establishment of guidelines for essential workers when forced to wear mask alternatives during a PPE shortage. Provided the current global situation of COVID-19 these studies indicate that homemade face masks do provide reduction of aerosol leakage. However, the fit and shape hinders their ability to reduce transmission even with implied social distancing.

4.3 Proper Mask Use and User Tendencies.

In most occupational settings, people are required to keep their face masks on for long work hours. The standard is a 40 - hour work week split up into five consecutive 8 – hour work days. It is no secret that wearing a face mask for 8 hours a day is an uncomfortable reality that many essential workers must face. The surge of face mask use globally for essential workers provides yet another area of study regarding user tendencies of face masks. Tendencies of the wearer could affect the overall ability of a mask to protect from COVID-19. For example, donning and doffing facemasks properly. Essential workers should be trained to place masks on correctly and carefully take them off. Proper hand hygiene and wear time are other factors that must be considered by all wearing masks and respirators.

Storage concerns for reusable and disposable masks may also be another factor of concern that may affect the efficacy of a mask. Other tendencies like not covering the nose and flipping a cloth mask inside out provide little to no protection against COVID-19. Similarly, taking the mask on and off throughout the for lunch, sips of their drink, and “mask breaks” may result in increased exposure likelihood.

4.3.1 Mask Use Guidelines in the United States.

Lisa Maragakis (2021), a researcher with John’s Hopkins Medicine explained the proper way to don a facemask beginning with the user washing their hands. The user must only touch the ear loops of the mask while placing it on the face, then they can touch the outside to place it in the correct position. After touching the outside for initial placement, the hands should be washed again. The reason for this procedure is to ensure that the user does not contaminate the inside of their mask. Essential workers that are not able to obtain disposable masks can resort to homemade, reusable cloth masks, according to Maragakis.

The CDC (2020a) specifies that respirators with two head straps should be removed with the bottom strap first, followed by the top strap. It is incredibly important that the outside of the mask is not touched, and the user’s hands are immediately washed. Healthcare workers are encouraged to remove gloves prior to removing respirators to eliminate chances of contamination. It is recommended that cloth masks should be washed after each use if the must be worn. With this, issues may arise when people are not motivated to wash their mask after each use, or if people just flip their mask inside out and call it clean.

Another crucial consideration outlined by the CDC (2021b) for good mask tendencies is to keep the nose and mouth covered completely. Without the nose covered by the cloth, the mask is essentially useless. They explain that clear face shields are not an alternative to masks as they provide no respiratory protection. They do encourage everyone to wear a mask when indoors in social settings regardless if one is feeling ill or not. The point of widespread mask usage is to minimize chances to spread COVID-19 by individuals who are asymptomatic while in public areas.

4.3.2 Mask Use in China.

In China, the originating country of COVID-19, a study was conducted to survey habits of mask wearers. Tan et al. (2020) addressed hand washing, donning/doffing, adjustments, repeated touching, wear time, and overall compliance. This also included the participants level of education and whether they were aware of good mask hygiene outlined by the Chinese National Health Commission, WHO and CDC. All participants self-reported their answers to the online survey, which was anonymous. The results were analyzed using statistical software which assigned a score for each answer category resulting in a total of 13 points for the best mask compliance.

Of the sample population in Tan et al (2020), 94% indicated that they knew how to don and doff a mask correctly from educational resources. However, other questions in the study suggested that individuals may not be following proper mask protocol even when educated. Overall, 96.5% of those surveyed indicated that they knew face masks covered both the nose and mouth. When asked "before putting on mask, did you wash your hands," 41.8% answered that they did not always clean their hands prior to donning a face mask.

Tan et al (2020) also concluded that 80% reported repeatedly adjust the mask when it is on. Out of this 80%, one half indicated that they did not wash their hand before or after adjusting the mask. Of their population, 92% also indicated that they touched the mask material, outside of adjustment, multiple times a day. Nearly half of the participants stated that they reused disposable masks for multiple day, and one third reported they do not store their mask in a well-ventilated area. One other interesting correlation seen by Tan et al was that individuals who were ill, exhibited the worst mask compliance and they reported adjusting and toughing their mask most frequently.

4.3.3 Comparison of Mask Use Tendencies in the U.S. and China.

While the statistics from this study may not be surprising, it is easy to draw a correlation between mask tendencies and decreased mask efficacy. According to Tan et al. (2020) those who do not wash their hands for donning/doffing, and while adjusting or touching their mask are increasing their chances of contracting COVID-19. The ability to cross contaminate between the inside and outside of the mask should be taken seriously within all working and public personnel. Wear time and storage are both important factors to consider as well. As previously stated, wear time differs between the type of mask and its intended use. Keeping a mask longer than its wear time, an 8-hour shift, could result in decreased filtration efficiency (Plog & Quinlan, 2012).

With further education, it is believed that poor tendencies of mask use can be changed. Individuals should be aware that touching and adjusting the mask repeatedly, can reduce the ability of the mask to act as a barrier. This should be stressed to individuals who are ill, as their immune systems are already compromised. It is very important that CDC guidelines on clean donning and doffing, mask handling, and proper hand hygiene are communicated to everyone.

Chapter 5: Discussion.

The purpose of this literature review was to determine if homemade face masks could be of comparable effectiveness to regulated respirators in the scope of COVID-19 protection. It is evident that there is not one single factor that influences the filtration efficiency of facemasks. Instead, it is a multifactorial science that seems to change with every new question that arises. One factor certainly seen across all studies is that the NIOSH rated respirators still provide the best protection. The N series masks are the most appropriate for protecting individuals from COVID-19 based on the characteristics of the aerosol and its size distribution. They provide the highest filtration efficiency for collecting particles 0.3 um in diameter. The way they form a seal around the breathing zone does not allow for large redirection of particles through the gaps. Surgical masks were variable across studies and their performance depended on the methods of each evaluation. When testing surgical masks, they were successful in stopping particles varying in diameter throughout the air stream. However, when it comes to fit, the performance can be poor.

Face masks constructed out of household filter and cloth materials performed decently in terms of material filtration. Although they do not offer protection like the NIOSH rated respirators. Hao et al. (2020) observed that they are generally 60% effective at filtering out aerosol particles from the user. Not all materials were created equal in their ability to provide good filtration efficiency. It was determined that loose woven fabrics with low thread count like bandanas and scarves, offer little protection regarding filtration capabilities. Multiple layers of cotton with a high thread count and a homemade filter, provided the highest filtration efficiency for home manufactured facemasks. While homemade facemasks can provide decent protection from COVID-19 aerosols, they may introduce their own risk of inhaling small fibers, which can lead to further respiratory complications.

The fit of each mask is an integral part of design and protection of essential employees and the public. Respirators like the N95, which seal to the face, are the best option. Those that do not create a seal, allow aerosol to enter the surrounding area up to a six-foot radius. Kolewe et al. (2020) demonstrated that primary areas in which masks exhibited vulnerabilities include the nose and cheeks. Although the N95 was the best fitting mask, it did show a slight weakness near the top of the nose. Masks with nose clips and pipe cleaners used for a better fit did improve the ability to contain aerosol generated by the user. Kolewe et al also included a vented mask in their research. While the vent is one way and protects the user upon inhaling, it allows a large number of particles to enter the environment while exhaling. This is important to consider as it essentially defeats the purpose of protecting others in a shared space.

As indicated by the CDC, poor tendencies regarding mask use can lead to a decrease in protection from COVID-19. Good hand hygiene is a must for proper donning and doffing (Maragakis, 2021). Without the practice of hand washing before and after toughing the mask, the user runs the risk of contamination from the outside of the mask to the inner side along the face (Tan et al., 2020). Constantly adjusting and touching the mask will also decrease its effectiveness and will contribute to contamination of the inside layer. As wear time increases, it is suspected that facemasks will lose their ability to protect users from aerosols (Plog & Quinlan, 2012).

Chapter 6: Conclusion.

In conclusion, it is evident that variables determining face mask filtration efficiencies and efficacy are wide spread. There is not one single contributing factor for the best filtration and fit, but instead is a combination of many. Overall, any mask was seen as a better alternative to a no mask at all. NIOSH rated masks of N95 and higher are the best all-around in terms of particle filtration and fit efficacy for the aerosol sizes that may contain the COVID-19 virus.

Research question 1 asks “do homemade face masks provide filtration efficiencies comparable to well established and regulated respirators?” This study indicates that homemade face masks are not comparable when strictly analyzing filtration efficiency of the material. However, there is merit to a homemade face mask providing a barrier to help slow the transmission of COVID-19.

Research question 2 asks “does poor fit of the face mask significantly decrease its ability to protect from COVID-19 transmission?” This study supports that poor fit does significantly decrease the efficacy of both face masks. It was determined that respirators with a seal provide the best protection from COVID-19 transmission based on size distribution of mask leakage.

Research question 3 asks “do poor user tendencies decrease efficacy of the face mask and increase the likelihood of COVID-19 transmission?” The material analyzed in this study supports that poor user tendencies do decrease the efficacy of the facemask, thus increasing the likelihood of COVID-19 transmission. Poor mask hygiene and tendencies like not washing and constantly removing the mask do decrease its lifespan.

Educational outreach should still be pursued and improved with the continuation of mask related studies. It is incredibly important that people are aware of the proper use, handling, and storage of face masks to increase their wear time and cleanliness. In the scope of COVID-19 and essential workers, face masks are integral to the health and safety of employees and surrounding individuals.

6.1 Future Implications.

In the future, more studies regarding the use of homemade face masks and their design should be carried out. For instances like a pandemic, it is best to have a firm foundational knowledge on which mask type and design will be protect people around the world. Although everyone is greatly affected, studies on essential workers like first responders and medical personnel should take priority as they are not able to socially distance. The effects of fiber inhalation on homemade cotton masks is an interesting topic that could become more prevalent as the pandemic continues to evolve. One can only imagine if populations will begin to exhibit respiratory irritations due to fiber dislodging of home manufactured face masks. The perfect homemade face mask is far from being determined and further research should be pursued.

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