ORIGINAL RESEARCH

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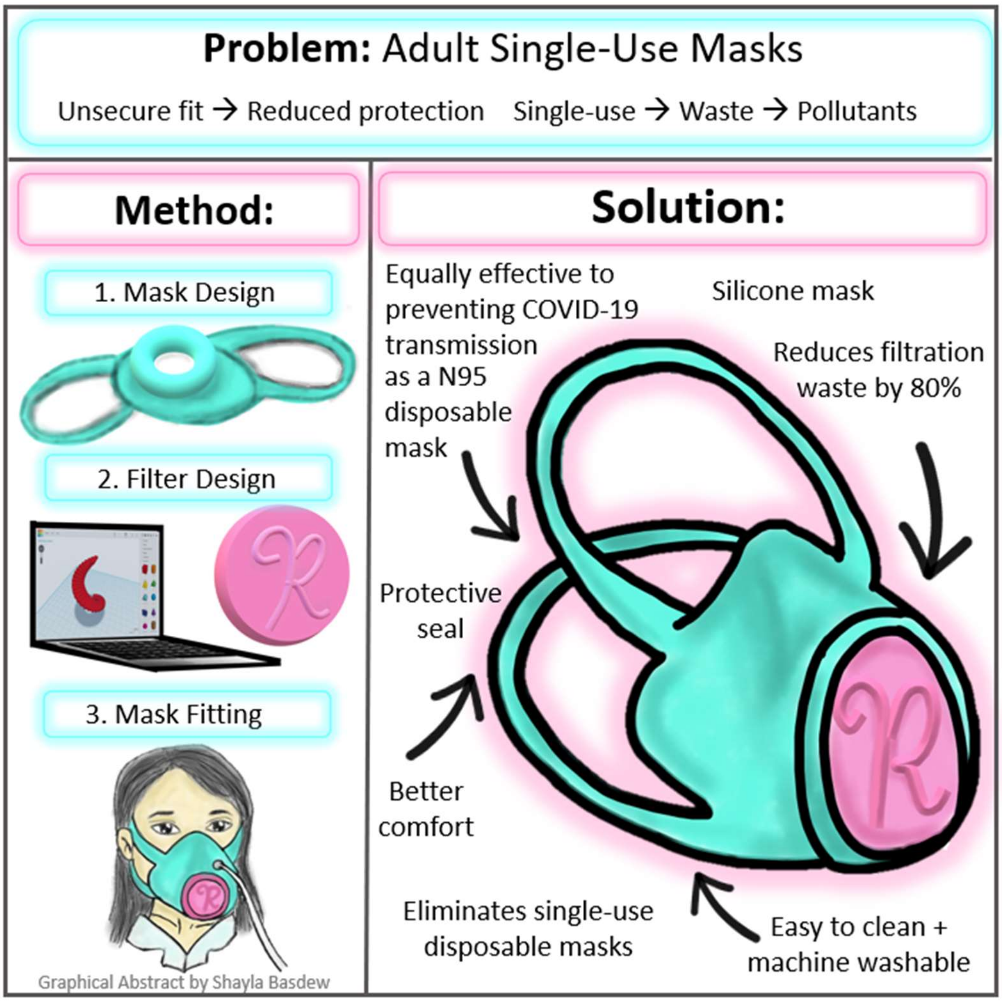

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3D Prototyping an Alternative Mask for Kids

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ABSTRACT

Due to the COVID-19 (SARS-CoV-2) pandemic, many children must wear masks at school to help reduce the spread of SARS-CoV-2 transmission. An investigation was conducted to develop an alternative reusable mask for kids with a protective seal and filtration. A 3D prototyped filter was designed and made to fit a 3D prototyped silicone mask. Different types of filter material were tested using a mask fit testing machine. In addition, a questionnaire was completed by 47 children aged 8 - 12 years old in order to understand their behaviours with masks at school. The reusable mask and filter proved as effective as a disposable N95 mask. Such masks could be cleaned by kids, reduce filter material waste by 80% and eliminate single use disposable masks. The 3D prototype mask and filter became an innovative engineering project that was designed, printed and processed by kids using local materials at home.

Keywords: COVID-19, mask, N95 mask, prototype filter, 3D printing, health inequalities, children's health

INTRODUCTION

SARS-CoV-2 is a respiratory virus that can spread through close contact from an infected person by respiratory droplets (droplets containing saliva or mucus from the respiratory tract, produced by actions involving the mouth and nose) or aerosols (droplets in the air) [1]. It can also be spread by surfaces contaminated with droplets [1]. The SARS-CoV-2 is incredibly small, with an average size of 80-120 nanometers, and can only be visualized through an electron microscope. When SARS-CoV-2 infects people, it can make them incredibly sick, potentially causing severe pneumonia and, in the worst cases, death [2]. Non-medical masks are effective for reducing the spread of SARS-CoV-2 to others by trapping the respiratory droplets through which the virus can be transmitted between people [3]. They can also successfully reduce the transmissibility of the virus to the wearer if they are made of an appropriate material and have an effective seal. The N95 respirator is the gold standard for mask use in the health care settings. This mask filters 95% of airborne particles in the air at 0.3 microns size [4].

During the early days of the SARS-CoV-2 pandemic, there was a large increase in demand for disposable N95 masks and surgical masks, causing major interruptions in global supply. Dr Christian Petropolis designed an N95 type mask to help doctors with the shortage in personal protective equipment (PPE) in Manitoba, Canada [5]. The mask design used a 3D printed mold to create a silicone mask with anaesthesia machine filters sourced from North America. Dr Petropolis mentored the researchers in the modification of his mask design to fit a new 3D prototype filter; he also aided in resizing the mask to fit kids.

When students returned to school, things were different due to SARS-CoV-2. Children wear masks in school for seven hours a day and maintain social distancing in the classroom [3]. Transmission of SARS-CoV-2 infections increases when people share an enclosed indoor environment with an infectious person for an extended time [6]. Given the limitations and costs of N95 masks and disposable surgical masks, it appeared that most kids have been using non-medical cotton or polyester reusable masks. The aim of this investigation had two purposes. The first was to conduct a questionnaire to understand the behaviours of kids with masks at school and their preferences of masks. The second was to develop an alternative reusable mask that would not only provide comfort, but also a protective seal and filtration from the SARS-CoV-2 virus. The use of a non-medical cotton or polyester reusable mask provides more limited protection from respiratory droplets which may contain SARS-CoV-2, and offers virtually no protection from inhaling the virus due to the lack of filtration and effective seal.

With the use of a disposable surgical mask, protection from spreading respiratory droplets is much higher, but it still does not effectively protect the wearer. However, a reusable N95 mask could successfully reduce spreading droplets to others, as well as protect the wearer [4]. It was therefore the aim of this project to design and prototype a mask that met that same standard.

Throughout the SARS-CoV-2 pandemic, the use of technology has allowed kids to attend school remotely, learn new skills and stay connected with friends and family [7]. Technology can also be used to improve intellectual wellbeing by learning new skills such as computer aided design (CAD) programs and 3D printing. The use of CAD programs allows ideas to be constructed in a virtual 3D model to design structures or prototypes. With the use of a 3D printer, the virtual 3D model can be printed within minutes to test the prototype in a physical environment. The researchers used readily available 3D printers at home, and materials to process the prototype mask and filter were available to purchase at local art suppliers or retailers.

Parents, children and teachers would all benefit from this project for three main reasons. Firstly, parents would not need to wash their kids' masks, and their children would be protected from the SARS- CoV-2 virus with a comfortable mask. Secondly, children would take ownership in their behaviours to protect themselves and others in a personalized and fun way. They could also gain skills in CAD design and 3D printing. Lastly, teachers would be more protected from students who may transmit the SARS-CoV-2 virus to them, thus creating a safer learning environment.

METHODS

200 grams of Smooth-On Dragon Skin 10 NV Part A and 2 grams of SLO-JO Platinum Silicon Cure Retarder were combined, and the desired amount of pigment and glitter was added. 200 grams of Smooth-On Dragon Skin 10 NV Part B was then added and mixed thoroughly. The mixture was placed in vacuum chambers in order to de-gas (remove air from) the mixture and reduce bubbles from forming. The silicone mixture was poured over the 3D printed mask mold and left to set. Once the silicone had set, it was removed from the mold. The mask was inspected for imperfections (bubbles or holes) and any extra material was removed.

Filter Design Procedure

Using a free online kids CAD program, Tinkercad, two types of filter prototypes were designed: one with an open face filter, and another with a custom design filter cover. The file has been provided open-sourced on Tinkercad for kids to learn and design their own filter. Once the filter prototype was designed, the file was converted from a Standard Triangle Language (STL) file to a G-code (a computer programming language used in computer-aided manufacturing), so the 3D printer could read the file and print it out in 3D using any colour polylactic acid (PLA) filament. PLA is a biodegradable and bioactive polyester material used in 3D printers. When the 3D print was finished, the circumference was measured to cut the different filter materials to fit. A smaller ring was printed and hot glued together to make a seal.

Fit Testing Procedure

A hole was pierced in the silicone mask with sharp scissors, and a grommet was secured and sealed with super glue. The fit test machine cloth was soaked in a solution of alcohol and inserted into the fit test machine. The researcher donned the mask, and the fit tester tube was connected to the grommet within the mask (Fig. 1). To ensure a secure mask seal, the tester blocked paths for air (the filter and grommet) and inhaled air in order to create negative pressure. If there were leaks, the mask was readjusted. The fit tester machine was set to release alcohol particles outside the mask for two minutes before collecting data. The different particle count readings were recorded from the fit test machine. Once data was collected, this was repeated with the different filter prototypes.

Figure 1 – Photograph of the researchers testing the 3D prototype mask and filters using a fit testing machine.

The filtration score of the 3D prototype mask and filters was tested by comparing the particles of alcohol in the mask with the particles of alcohol outside the mask. The six different prototype filters were compared with a disposable N95 mask and no filter at all. A range of data from high particle counts and low particle counts were collected, and the median particle count was calculated. A pass-fail level was determined by analyzing the high particle count and using the N95 disposable mask high particle count as a threshold. Levels above the filtration score failed the test, while levels below passed based on an acceptable level of particles within the mask.

Student Questionnaire

A questionnaire of 47 children, ages 8 - 12 years old, was completed to understand their behaviours with masks at school and their understanding about the SARS-CoV-2 virus. The gathered information was used to improve reusable masks for kids. Participation was voluntary and was done with informed consent. The data collected from the different age groups was analyzed as a collective sample.

RESULTS

The filtration score of the 3D prototype mask and filters was tested by comparing the particles of alcohol in the mask with the particles of alcohol outside the mask. The six different prototype filters were compared with a disposable N95 mask and no filter at all. A range of data from high particle counts and low particle counts were collected, and the median particle count was calculated. A pass-fail level was determined by analyzing the high particle count and using the N95 disposable mask high particle count as a threshold. Levels above the filtration score failed the test, while levels below passed based on an acceptable level of particles within the mask.

When the 3D prototype mask and filters were tested on the fit testing machine, data of the high and the low particle count was collected. The filtration score of the 3D prototype mask and filters was tested by comparing the particles of alcohol in the mask to the particles of alcohol outside the mask. An N95 disposable mask and a mask with no filter both served as controls and were compared to the six different prototype filters. A range of data from high particle counts and low particle counts were collected, and the median particle count was calculated (Fig 2). A pass-fail level was determined by analyzing the high particle count and using the N95 disposable mask high particle count as the threshold level to pass (Fig 3). Levels above the level set by the N95 disposable mask failed the filtration score, due to the high level of particles entering the mask. The mask with no filter and the covered filter prototype with a one-layer N95 grade filter material failed the filtration score. The other five filters successfully passed the test with a filtration score lower than that recorded for the N95 mask. This experiment showed that the 3D prototype alternative mask and filter was similar to a N95 disposable mask, because it achieved a seal and filtered out the particles below the level set by the N95 mask control.

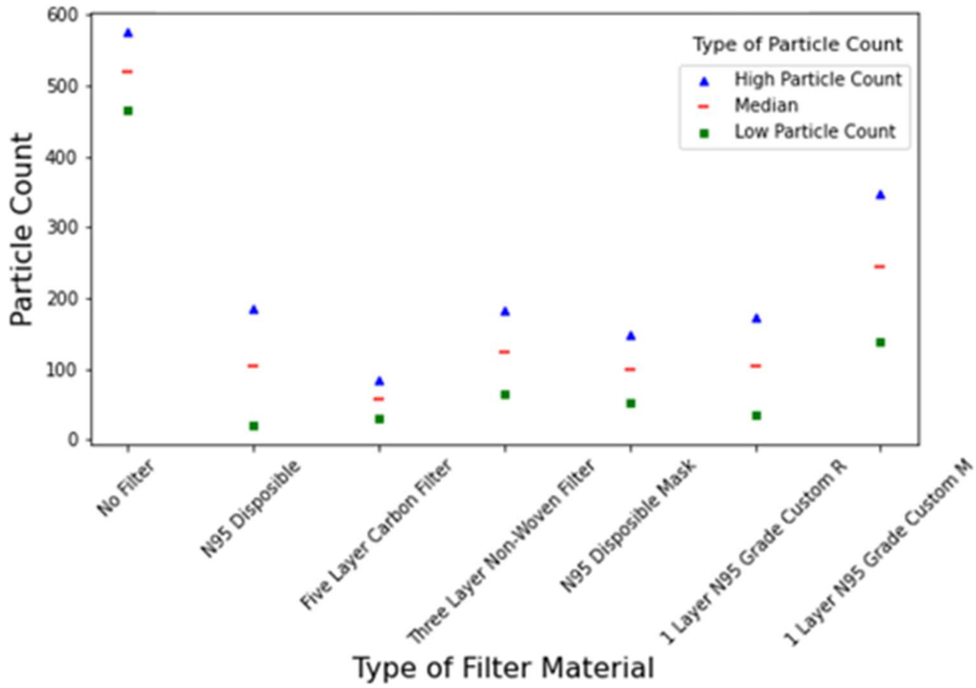

Figure 2 – 3D prototype mask fit test. A plot graph showing the data collected of high and low particle counts from the different prototype filters tested on the fit tester machine. The median particle count was calculated from the range of data. Figure created by Mark Giroux.

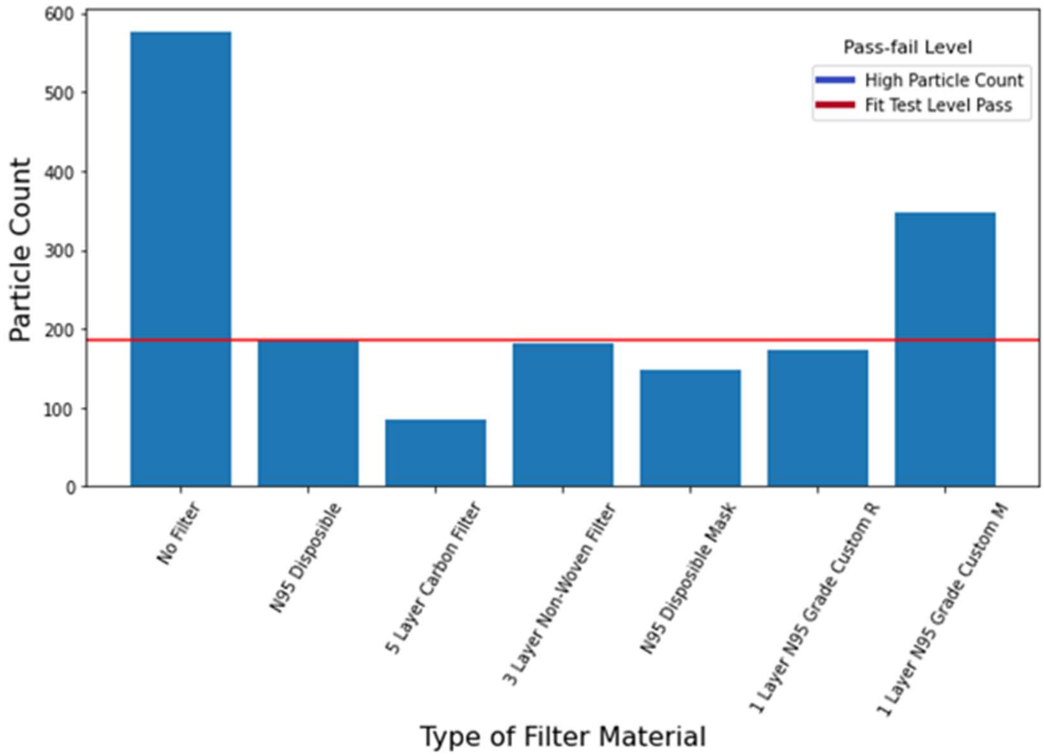

Figure 3 – Mask fit test pass-fail level. A bar graph comparing the high particle count of each filter material with the fit test pass level threshold determined by the disposable N95 mask. Filter materials that were below the level passed the acceptable level of particles entering the mask. Figure created by Mark Giroux.

After fit testing the six prototype filters, it was found that the open face filter prototype with a one-layer N95 grade filter sourced from North America filtered the particles best. Next was the open face filter prototype with a five-layer carbon filter sourced from overseas; then the open face filter prototype with an N95 disposable mask filter sourced from North America; followed by the covered filter prototype with a one-layer N95 grade filter sourced from North America; and the open face filter prototype with a three-layer nonwoven filter sourced from overseas. Lastly, the covered filter prototype with a one-layer N95 grade filter sourced from North America failed the filtration score.

To understand how masks were affecting children in school, a sample of student ages 8-12 years old were offered a voluntary paper questionnaire in select Manitoba schools. Out of the 47 children who participated in the questionnaire, it was found that 80% of kids wore reusable cotton or polyester masks, and 50% of kids did not change their masks throughout the day. 33% of kids changed their mask once a day, and 17% changed it twice a day. It is recommended that children change their masks once it is wet or soiled and change to a new mask after a snack and lunch time [3]. Therefore, children should change their mask a least three times a day while at school and have new clean masks available for the following school day.

The top three complaints about masks were that they are hard to breathe in, they get wet, and they are uncomfortable. Kids also complained that their masks fall off their nose, they are loose fitting, and they hurt their ears. It was also clear that 70% of kids think that wearing a mask will protect them from getting the SARS-CoV-2 virus. This suggests that children need to be educated on how the virus can be spread and what they can do to protect themselves and others. Specifically, it is important for them to understand the difference between respiratory droplets and the aerosol transmission of the SARS-CoV-2 that can spread from an infected person when wearing a mask without proper fit and filtration.

A mask needs to have a filter and a tight fit or seal to protect kids from getting SARS-CoV-2. Wearing a non-medical cotton or polyester mask may prevent respiratory droplets from spreading, but it still allows SARS-CoV-2 to enter the mask. Not all masks give the same protection – a mask should have a seal and a filter with more than one layer to stop the spread of SARS-CoV-2. The reusable 3D prototype mask and filter was easy to clean and changing the filter was simple. During the day, it could be wiped clean with alcohol, and the filter changed to a new one. At the end of the day, the mask could be washed in the dishwasher, and it was ready for use the following day.

DISCUSSION

A total of six prototype filters were designed: four open face filter prototypes and two custom design filter covers. Four different filter materials were used and tested with the six prototype filters: an N95 disposable mask, a five-layer carbon filter, a one-layer N95 grade filter, and a three-layer nonwoven filter. The different filter materials were sourced from both overseas and North America, and purchased at local retail suppliers.

It was hypothesised that the open face filter with the five-layer filter would provide the best filtration when compared to a disposable N95 mask. The findings were different to the hypothesis as it was thought that the more layers the filter had, the better the filtration would be. However, it seems the grade of material is a major determining factor and the melt blown N95 grade filter does provide excellent filtration.

The interruption in global supplies of PPE and everyday items during the early pandemic demonstrated the reliance on overseas manufacturing and imports. It is important to promote local economies in the manufacturing and sourcing of products. The silicone and filter materials used for the most effective prototype mask and filter were sourced from North America and could provide an alternative to masks and materials sourced from overseas. The prototype mask and filter has several benefits such as the low cost to make the reusable N95 type mask for kids; also, the prototype filter uses 80% less filter material than a disposable surgical mask. This reusable 3D prototype mask and filter could reduce waste during the pandemic. In reducing the amount of filter material per single use, and prompting the use of a reusable mask, the amount of waste produced by single use products imported from overseas can be reduced, which would minimize pollution and loss of local economic growth. The materials for the silicone mask, the 3D printer filament for filter prototypes and the filter material would cost about $7 for each 3D prototype mask and filter.

A future project would be to create a silicone mask fitter. This option would provide a seal for a disposable surgical mask, giving both a seal and filtration for the person wearing the mask. The materials needed to make a kids silicone mask fitter would cost about $3. This option would use less silicone material, would be quicker to produce than the 3D prototype mask, and would be more accessible to kids who want to choose their own disposable mask.

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AUTHOR'S NOTE

All figures, or tables, were created by the Author, unless otherwise mentioned in the description provided of said figure.

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