PEER REVIEW HISTORY

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ARTICLE DETAILS

TITLE (PROVISIONAL)	Ability of Fabric Facemasks Materials to Filter Ultrafine Particles at Coughing Velocity
AUTHORS	O'Kelly, Eugenia; Pirog, Sophia; Ward, James; Clarkson, John

VERSION 1 - REVIEW

REVIEWER	Dr Bhanu Bhakta Neupane Tribhuvan University, Nepal
REVIEW RETURNED	05-May-2020

GENERAL COMMENTS	There are many issues in this paper. Almost all the problem/questions identified in this paper is already explored and published in literature (please see comment 10). 1) The N95 respirator is reported to have very low filtering efficiency (~53%). I have not seen any papers reporting that low efficiency. The size of particles claimed here is similar to Sande et al (Ref. 6) and Rengasam et al (Ref. 5) work. The most penetrating particle size (MPS) for elect filter (filter medium of N95) is 0.1-0.5 micrometer and N95 is designed to give at least 95% efficiency even for the MPS. 2) This paper lacks lot of experimental details. How the sample was mounted in the sample holder? Most likely the low efficiency is due to improper fit of N95 filter in the sample holder. If measurement error is not the issue, author should have provided a clear explanation for lower FE of N95 and even for surgical mask. 3) What was the loading time and humidity in the measurement? This is importantIs high flow rate a issue? Comparison of the measurement method with the standard NIOSH test method (or other test methods) should be made before claiming that "Numbers in this experiment should be interpreted as low baselines, representing material performance at high levels of stress rather than normal respiratory rates" [page 5, line 53-55] 4) The particle size distribution information is not consistent. Somewhere it is said less than 1 micrometer (in objective section) and in text less than 0.1 micrometer. It has to be supported by data. 5) In page 5, line 30: Tests were conducted as described by Hutten [6]. Reference 6 is not by Hutten. Schematics of the measurement set up is very important but missing here.

	6) In line 5, the expression of FE not correct, should be FE= (a-b)100/a; parenthesis in numerator is missing. 7) Page 7, line 7: The filtration efficiencies of select materials were tested when damp (see Figure 2). I do not see figure 2. 8) In figure 1 why efficiency is reported in fraction? 9) In page 9, line 13-15:The difference between ultrafine particle filtration of the surgical masks, t-shirt fabric,and a woven cotton tested in this study and the viral filtration of the surgical mask, t-shirt, and mixed woven cotton seen in Davies et al.'s study were proportionally similar[2]. The conclusion made is very loose generalization. Ref. 2 is wrongly cited. 10) There are some interesting recent studies made that relate the filtering efficiency of many types of fabrics to material property, for example thread density and pore size, and other issues in details. Neupane BB, Mainali S, Sharma A, et al. Optical microscopic study of surface morphology and filtering efficiency of face masks. PeerJ 2019;7:e7142. Konda A, Prakash A, Moss GA, et al. Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. ACS Nano 2020. Because of above reasons I would not recommend this paper to publish in BMJ open.

REVIEWER	Christopher K. Brown, PhD, MPH, CPH Occupational Safety and Health Administration, United States (review completed in personal capacity).
REVIEW RETURNED	18-May-2020

GENERAL COMMENTS	Please see additional specific comments in PDF markup, in the attached. The reviewer has some questions about the methodology, which should be answered in a revision to the article. These questions relate to how the airflow rate was selected, how dampness was determined, and whether or not the particle counter's size limitations were appropriate. The comments also note some confusion about the references used, which require minor clarification or potentially adjustment/correction of the citation numbers. Somewhere early in the introduction, the article should distinguish between masks worn to meet the objective of the current CDC recommendation, which is source control (i.e., containment of the wearer's potentially infectious respiratory secretions or droplets) versus masks worn for the wearer's protection (i.e., to filter out potentially infectious particles from the outside before they are inhaled). The authors should also add additional explanation about their results, which compare improvised mask materials' filtration capabilities to those of N95 respirators. This may lead readers to make the wrong conclusion about the protectiveness of various options. A vacuum cleaner bag constructed of HEPA filter material

	may have filtered more fine particles in the setup of this experiment, but the authors should make it clear that vacuum bags, when used as improvised face masks, do not seal to the face like a properly fitted N95 respirator would, so leakage around the mask would likely contribute more total exposure to particles compared to the N95 respirator. The experimental results should not be used for direct application to clinical/community settings, in this case. The reviewer provided a marked copy with additional comments. Please contact the publisher for full details.

VERSION 1 – AUTHOR RESPONSE

Reviewer's Comment - Notes	Changes Made	Authors' Comments
The N95 respirator is reported to have very low filtering efficiency (~53%). I have not seen any papers reporting that low efficiency. The size of particles claimed here is similar to Sande et al (Ref. 6) and Rengasam et al (Ref. 5) work. The most penetrating particle size (MPS) for elect filter (filter medium of N95) is 0.1-0.5 micrometer and N95 is designed to give at least 95% efficiency even for the MPS.	Highlighted the difference in testing methodology, namely the higher velocity to represent coughing. These changes can be seen in the introduction, methods, and discussions section. Included data on low-velocity N95 calibration tests Included new figure in discussion section comparing data from three main studies on fabric filtration and our study with adjusted velocity to 0.19 m/s	I believe we failed in our first version to highlight the significance of our chosen velocity. Prior studies used velocities similar to those in NIOSH testing methods. These low velocities of 0.1 m/s and 0.25 m/s represent velocities exhaled during sedate to active breathing. Coughing has a velocity which can be over 100 times greater this. Because face masks are used to protect others as well as the wearer, it is critical that we understand how well the face mask filters particles at the much higher velocities seen in coughing. The ability of masks to filter at high velocities has not been well studied. Our study is the first contribution to the topic of fabric face mask filtration which evaluates filtration at coughing velocities. There is very little literature on high velocity filtration, as NIOSH and other standards use low velocities. However, one study by Renasamy shows that n95 masks ability to block artificial blood dropped as

		velocities increased by 1.4 times. Furthermore, a project at Delft University of Technology observed a drop in FE at higher face velocity.

This paper lacks lot of experimental details. How the sample was mounted in the sample holder? Most likely the low efficiency is due to improper fit of N95 filter in the sample holder. If measurement error is not the issue, author should have provided a clear explanation for lower FE of N95 and even for surgical mask.	We have added several new paragraphs to the Methods Section and added details to existing sections Added a diagram of the testing-apparatus to methods section Added discussion of low-velocity n95 tests to methods section, introduction, and discussion	We believe the low filtration efficiency of the N95 mask is due to the high velocity used in this study. We tested the apparatus at a low velocity and achieved an average 89% FE and high of 93% FE, which was higher than Konda but lower than Rengasamy. Unfortunately, we did not record the velocity during these tests. As shown in the discussion, when results are proportionally adjusted to account for velocity, our average FE for N95 masks was 95%.
What was the loading time and humidity in the measurement? This is important as high flow rate is an issue? Comparison of the measurement method with the standard NIOSH test method (or other test methods) should be made before claiming that "Numbers in this experiment should be interpreted as low baselines, representing material performance at high levels of stress rather than normal respiratory rates" [page 5, line 53-55]	- Loading time was added to method - High flow rate is discussed in introduction, methods, and discussion - Comparison of the NIOSH and other test method in discussion section - Confusing sentence about "low baseline" omitted, replaced with concrete comparisons	Humidity was not in the measurement, but tests were conducted back-to-back in the same temperature-controlled room. Unlike in NaCl tests, no vapor producing particle generator was used which would increase humidity over time.

The particle size distribution information is not consistent. Somewhere it is said less than 1 micrometer (in objective section) and in text less than 0.1 micrometer. It has to be supported by data.	- Typo corrected - "and less than" added	Thank you for catching this. This was a typo - particle size should always read 0.1 micrometre
In page 5, line 30: Tests were conducted as described by Hutten [6]. Reference 6 is not by Hutten. Schematics of the measurement set up is very important but missing here.	Schematics added. Reference number corrected.	
In line 5, the expression of FE not correct, should be FE= (a-b)100/a; parenthesis in numerator is missing.	Corrected with parenthesis added in numerator	
Page 7, line 7: The filtration efficiencies of select materials were tested when damp (see Figure 2). I do not see figure 2.		It seems there might have been some problem with seeing Figure 2, which was imported from R. Some people who got the Word document could see it while others could not. We are going to uploaded it as both a Word and PDF to try and resolve this issue.

In figure 1 why efficiency is reported in fraction?	FE now reported as a percentage	
In page 9, line 13-15:The difference between ultrafine particle filtration of the surgical masks, t-shirt fabric, and a woven cotton tested in this study and the viral filtration of the surgical mask, t-shirt, and mixed woven cotton seen in Davies et al.'s study were proportionally similar[2]. The conclusion made is very loose generalization. Ref. 2 is wrongly cited.	- Sentence with vague generalization removed - New section added to discussion section - All references have been corrected	This was indeed poorly worded. It has now been replaced by a new section in the discussion section which discusses the relationship between the various studies on fabric mask filtration.

There are some interesting recent studies made that relate the filtering efficiency of many types of fabrics to material property, for example thread density and pore size, and other issues in details. Neupane BB, Mainali S, Sharma A, et al. Optical microscopic study of surface morphology and filtering efficiency of face masks. PeerJ 2019;7:e7142. Konda A, Prakash A, Moss GA, et al. Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. ACS Nano 2020		Konda was published three weeks or so after we submitted to the BMJ. We have now incorporated Konda's paper and data. Neupane's study is a valuable analysis, but as they purchased the masks at a local market and do not know the fibre content, it is not feasible to make a comparison with specific fibres. We have, however, included Neupane in our discussion of washing and drying on FE.

Reviewer's Comment - Notes	Changes Made	Authors' Comments
Page 5, Line 12 What is meant by [green zone]?	Changed to "their homes". Sentence now reads: "Despite this severe shortage, many areas have begun requiring the use of face masks for individuals who leave their homes."	There are growing calls for people to wear face masks from multiple countries. The UK has made it mandatory for all individuals to wear face masks when on public transport or in a hospital. The US continues to mandate face masks for individuals leaving their house.
Page 5, Line 46 What does this terminology [in-hospital] mean? Is this referring to masks intended for medical settings? Please clarify	Changed to "Masks intended for use during medical procedures…"	
Page 5, Line 46 Write out [CDC] on first use.	CDC now introduced as Center for Disease Control (CDC)	
Page 5, Line 47 Is this correct? The reference provided does not point to information on re-use (did the authors mean to cite reference #4 here?). In any case, if this is referring to U.S. Centers for Disease Control and Prevention guidance, re-use is part of contingency/crisis strategies for optimization respirator supplies. Re-use should be an option reserved for when it is absolutely necessary. This reviewer's understanding is that the CDC is not recommending re-use if possible, only when necessary.	Changed reference number Clarified study importance in light of CDC recommendations. Section on mask re-use ended up being cut during edits made to the introduction.	We ended up re-writing parts of the introduction to better highlight the significance of this study and its unique contribution.

Page 4, Line 3-4 Somewhere early in the introduction, the article should distinguish between masks worn to meet the objective of the current CDC recommendation, which is source control (i.e., containment of the wearer's potentially infectious respiratory secretions or droplets) versus masks worn for the wearer's protection (i.e., to filter out potentially infectious particles from the outside before they are inhaled).	Added a sentence to this effect in paragraph 3. New sentence: "Furthermore, the primary purpose of face masks worn by the general public is to limit the spread of viral particles from respiratory activity, rather than blocking the inhalation of any contagious particles, for which the CDC recommends cloth coverings [citing CDC]."	Thank you for reminding us to clarify this for readers. Many of the individuals who reach out to us do not understand the importance of preventing viral spread to others through the wearing of face masks even when asymptomatic.
Page 4, Line 25-26 Did this not lead to varying dampness among the materials, depending on their composition? E.g., 7 mL on lightweight cotton seems like it would result in greater wetness than 7 mL on thickly felted wool.	New sentences: The 7 milliliters of water was intended to represent the approximate amount of water exhaled during one hour of respiration [Zlielinski and Przybylski, 2012]. The water affected each material differently according to their properties to resist or absorb moisture.	This did indeed lead to differing levels of dampness. For example, the wool resisted water quite well while the denim soaked it in immediately. Our team discussed methods of testing dampness and decided upon this method as it preserved the fabric's natural ability to repel or absorb water and thus better reflected the ability of the material to cope with dampness generated by respiration. The amount of absorption and spread indeed differed according to fabric. These differences would be reflected in actual use.

Page 4, Line 32 It seems like this misses a significant proportion of potentially infectious particle sizes, from 0.1 µm to 0.5 µm typically associated with airborne transmission and >0.5 µm typically associated with droplet transmission. More discussion of this would be useful.	This is indeed a weakness of the study. Due to University laboratories being closed, we rented our equipment from a commercial supplier. We had limited funds, and decided to rent ultra-fine particle counters as a precaution. The best particle counter available which could assess ultra-fine particles had an upper limit of 0.1. We believed it was better to get the best equipment possible on the market today and limit the particle distribution tested. Furthermore, prior studies show the lowest particle filtration percentages occur with smaller particles. This would allow us to err on the side of caution - giving the public the lowest filtration percentages. Finally, ultra-fine particles are of the greatest importance in other emergencies where masks supply has historically not meet demand, such as during forest fires and pollution spikes.	
Page 4, Line 35 Why was this velocity chosen? This seems higher than the velocity associated with normal breathing and much lower than sneezing. Please explain here. It seems like the later paragraphs link this to coughing, but might be better to address the velocity earlier in the paper.	Paragraph added to the introduction Section added to the methods Section added to the discussion section	We have highlighted the significance of our chosen velocity and why it makes this paper an important addition to the literature on cloth face masks. We feel we failed to properly highlight this previously – thank you for raising this point.
Page 4, Line 41 Upstream and downstream particle count should probably be defined for clarity.	Diagram (Figure 1) added to clarify upstream and downstream	
Page 5, Line 4 This is a key limitation to the study that should probably also be addressed in the conclusions. For the COVID-19 pandemic, it might be useful to couch this in what it means for preventing mask wearer exposure to the larger respiratory droplets believed to contribute most significantly to the virus' transmission, compared to smaller aersolized particles or droplet nuclei.	We removed this section from the methods and introduced a more detailed discussion of the limits to the study into the discussion section, where we believe it is better placed.	
Page 5, Line 21 This paragraph probably belongs in the discussion section.	Paragraph has been moved to the discussion section	

Page 5, Line 40 Was this because Kenmore was the brand available, or is this in comparison to other brands of vacuum bags? If the former, you may want to mention that, and that you aren't endorsing some particular brand.	Removed the mention of the brand's name from the main text and included it along with the other brands in Figure 2. We have reformatted all the branded materials in Figure 2 to consistently list brand information.	Kenmore was the band available. Thank you for pointing this out
Page 8, Line 27 Do these vacuum bags contain any potentially toxic chemicals that would off-gas during wear?		We have not found any research or indications that off-gassing would occur. The main concern seems to be fiberglass particles, which would be dangerous when inhaled. In response to COVID many manufacturers are ensuring their product's safety, but without independent analysis or a full disclosure of all materials used we would advise caution.

VERSION 2 – REVIEW

REVIEWER	Dr Bhanu Bhakta Neupane Tribhuvan University, Nepal
REVIEW RETURNED	28-Jul-2020

GENERAL COMMENTS	Authors have significantly improved the manuscript. However, they still need to address the following concerns. Major concerns: 1) Include some of the major findings in the abstract section; report some data 2) How the particles used in this study were generated?What is the nature of the particles?I hope authors have some sort of curves or data that shows the particle size distribution.This is very important issue. Please include this information in the experimental section. 3) Provide the missing details on the breathing resistance study. For example, how many people were involved in the tests (size of the team)? I believe, the method used here is not standard. Please say it clearly. If similar method is reported else, please cite the appropriate reference. 4) Provide the detail information of the particle counter and the face velocity meter. The standard way of reporting is (instrument name, company name, country of origin, part/model). The information is partly included in figure caption 1; rather put the detail information in the experimental section. 4) Author say that the "velocity for the calibration test was not recorded" (page 5 line 24-25). It is very important to have at least a

	rough estimation of the face velocity here. Minor corrections; 1)Page 3 line 14: change the word "select" to "selected". 2) Page 3 line 14: change the word "access" to "access to". 3) Page 4, Line 10-11: Improve the sentence "Despite this severe shortage, many areas have begun requiring the use of facemasks for individuals who leave their property. 4) Page 4 line 12-13: Facemasks are made mandatory in many countries. Please modify the following sentence accordingly. 5) Page 4, 42-43: Put appropriate references at the end of the sentence. 6) Though out the manuscript be consistent with the word "Facemasks" or "Face masks". 7) page 5, Line 16-18: The sentence "As such,priority was given to developing a test apparatus which could be constructed and provide usable...." is not true. The scope of the paper is different. Please correct this. 8) Through out manuscript "et al" is wrongly written as "et all". Make changes in all places. 9) The words "facemask construction" is odd. Replace with "facemask design" throughout the manuscript. 10) page 9, line 54-55: what is the shape of the data mean here? Put reference(s) at the end of sentence.

REVIEWER	Christopher K. Brown, PhD, MPH, CPH Occupational Safety and Health Administration (OSHA), United States (review performed in a personal capacity and does not reflect the view of the U.S. Department of Labor/OSHA)
REVIEW RETURNED	08-Jul-2020

GENERAL COMMENTS	No further comments on this paper. The authors appear to have addressed the significant comments from the previous round of review, and the paper will provide readers with useful information about facemask material if published.

VERSION 2 – AUTHOR RESPONSE

To reviewer Bhanu Bhakta Neupane

We have done our best to respond to your concerns. I believe we have been able to address all of your concerns in the revised manuscript. All minor corrections were made.

Below we have broken down our changes:

Reviewer's Comment	Changes Made
1) Include some of the major findings in the abstract section; report some data	We made significant changes to the Results section of the abstract, including summary data and highlighting important take-aways we felt the prior abstract might have failed to bring to the reader's attention.
2) How the particles used in this study were generated? What is the nature of the particles? I hope authors have some sort of curves or data that shows the particle size distribution. This is very important issue. Please include this information in the experimental section.	We have included information in the method section regarding particle generation. We raised ambient particle levels through by aerosolizing NaCL. We have included the solution, device used, and flow rate. We have included more precise information on the measured particle sizes in the methods section. We also included a discussion about the chosen particle range and what respiratory particles of interest fall within this range. We decided to focus on measuring particles of this size due to a growing body of research which indicates that spread of respiratory viruses may be primarily due to small particles, rather than larger particles and droplets as originally believed.
	Sadly, we do not have a graph that shows the exact particle size distribution. While this would certainly be helpful for some readers, we do not believe the lack of this information limits the impact and usefulness of the paper for the majority of readers. Here are some reasons: (1) We are already testing a small range of particles (0.02-0.1), and thus our data inherently has a high granularity. (2) Our selected size range covers the most critical respiratory viruses. The pathogenic particles (coronavirus, influenza, etc) which are the main interest to this paper, all fit on the larger end of the measurements taken and will thus be safely accounted for in the given measurements. (3) Prior studies on fabric filtration, such as those by Van der Sande and Neupane, do not contain any particle size distribution

	information yet include a much wider range of particle sizes.
3) Provide the missing details on the breathing resistance study. For example, how many people were involved in the tests (size of the team)? I believe, the method used here is not standard. Please say it clearly. If similar method is reported else, please cite the appropriate reference.	We added additional details to the methods section regarding how breathing resistance was estimated. Number of people involved in the breathing resistance was already stated. We added new information on testing and agreement. This is not a standard method, but it provided an accurate approximation of how much breathing resistance a material offered. We chose this method as one those creating fabric masks could reproduce.
4) Provide the detail information of the particle counter and the face velocity meter. The standard way of reporting is (instrument name, company name, country of origin, part/model). The information is partly included in figure caption 1; rather put the detail information in the experimental section.	We added the requested information to the Methods > Testing Apparatus section of the paper. Information has been entered into paper as: P-Trak, TSI, United States, model 8525 & VelociCalc Ventilation Meter, TSI, United States, model 9565
4) Author say that the "velocity for the calibration test was not recorded" (page 5 line 24-25). It is very important to have at least a rough estimation of the face velocity here.	Our lab books say velocities ranged from 5.5 m/s to 7.5 m/s during low-velocity calibration. We have updated the Methods section to include these numbers. We have also re-run the calibration to confirm.

VERSION 3 – REVIEW

REVIEWER	Dr Bhanu Bhakta Neupane Central Department of Chemistry, Tribhuvan University, Kathmandu, Nepal
REVIEW RETURNED	17-Aug-2020

GENERAL COMMENTS	The authors have addressed all the concerns, so I recommend this article for publication. I do not need to see it again. However, please note the following minor changes. 1) Page 2: Modify the sentence "The average filtration efficiency of single layer fabrics 32% and average layered combination was 45%" to "The average filtration efficiency of single layer fabrics and average layered combination was found to be 35 and 45%, respectively. 2) Everywhere in the text change "NaCL" to "NaCl". 3) Change the sentence (Page 22 Line 47) "Ambient particle levels were raised by nebulizing NaCL with a Pari Pro Plus, Vios, United States, 312F83-LC+ nebulizer, with a total output rate of 590 mg/min" will change to "The aerosol particles were generated by nebulizing NaCl with a nebulizer (Pari Pro Plus, Vios, United States, 312F83-LC+) at the total output rate of 590 mg/min. 4) Change the sentence (page 23 at Line 33) "Velocity was measured with VelociCalc Ventilation Meter, TSI, United States, model 9565" to "Velocity was measured with VelociCalc Ventilation Meter (TSI, United States, model 9565)".