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The National Academies of
SCIENCES • ENGINEERING • MEDICINE

April 8, 2020

Kelvin Droegemeier, Ph.D.
Office of Science and Technology Policy
Executive Office of the President
Eisenhower Executive Office Building
1650 Pennsylvania Avenue
Washington, DC 20504

Dear Dr. Droegemeier:

Attached please find a rapid expert consultation that was prepared by Rich Besser and Baruch Fischhoff, members of the National Academies' Standing Committee on Emerging Infectious Diseases and 21st Century Health Threats, with input from Sundaresan Jayaraman and Michael Osterholm. Details on the authors and reviewers of this rapid expert consultation can be found in the Appendix of the attachment.

The aim of this rapid expert consultation is to respond to your request concerning the effectiveness of homemade fabric masks worn by the general public to protect others, as distinct from protecting the wearer. The request stems from an interest in reducing transmission within the community by individuals who are infected, potentially contagious, but asymptomatic.

Overall, the available evidence is inconclusive about the degree to which homemade fabric masks may suppress spread of infection from the wearer to others. For as long as homemade fabric masks are in use by the public, the investigations outlined at the end of the rapid expert consultation could reduce uncertainty about the effectiveness of these masks.

My colleagues and I hope this input is helpful to you as you continue to guide the nation's response in this ongoing public health crisis.

Respectfully,

Harvey V. Fineberg, M.D., Ph.D.
Chair
Standing Committee on Emerging Infectious Diseases and 21st Century Health Threats

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

April 8, 2020

This rapid expert consultation responds to your request concerning the effectiveness of homemade fabric masks worn by the general public to protect others, as distinct from protecting the wearer. The request stems from an interest in reducing transmission within the community by individuals who are infected, potentially contagious, but asymptomatic or presymptomatic. As discussed below, the answer depends on both the masks themselves and how infected individuals use them.

The following analysis is restricted to the effectiveness of homemade fabric masks, of the sort illustrated in recommendations[1] directed at the general public, in terms of their ability to reduce viral spread during the asymptomatic or presymptomatic period. It does not apply to either N95 respirators or medical masks.

In considering the evidence about potential effectiveness of homemade fabric masks, it is important to bear in mind how a respiratory virus such as SARS-CoV-2 spreads from person to person. Current research supports the possibility that, in addition to being spread by respiratory droplets that one can see and feel, SARS-CoV-2 can also be spread by invisible droplets, as small as 5 microns (or micrometers), and by even smaller bioaerosol particles.[2] Such tiny bioaerosol particles may be found in an infected person's normal exhalation.[3] The relative contribution of each particle size in disease transmission is unknown.

There is limited research on the efficacy of fabric masks for influenza and specifically for SARS-CoV-2. As we describe below, the few available experimental studies have important limitations in their relevance and methods. Any type of mask will have its

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[1] Centers for Disease Control and Prevention (CDC) Recommendation Regarding the Use of Cloth Face Coverings, Especially in Areas of Significant Community-Based Transmission in response to COVID-19 https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover.html

[2] Gralton and colleagues (2011) noted the following in regards to particulate size and the importance of airborne precautions whenever there is a risk of both droplet and aerosol transmission: "Regardless of the complexities and limitations of sizing particles and the contention of size cut-offs, it remains that particles have been observed to occupy a size range between 0.05 and 500 microns. Even using the conservative cut-off of 10 microns, rather than the 5 micron to define between airborne and droplet transmission, this size range indicates that particles do not exclusively disperse by airborne transmission or via droplet transmission but rather avail of both methods simultaneously. This suggestion is further supported by the simultaneous detection of both large and small particles. In line with these observations and logic, current dichotomous infection control precautions should be updated to include measures to contain both modes of aerosolised transmission. This may require airborne precautions to be used when at risk of any aerosolized infection, as airborne precautions are considered as a step-up from droplet precautions." Gralton, J., et al. 2011. The role of particle size in aerosolised pathogen transmission: A review. J Infect 62(1):1-13.

[3] National Research Council. 2020. *Rapid Expert Consultation on the Possibility of Bioaerosol Spread of SARS-CoV-2 for the COVID-19 Pandemic (April 1, 2020).* Washington, DC: The National Academies Press. https://doi.org/10.17226/25769.

own capacity to arrest particles of different sizes. Even if the filtering capacity of a mask were well understood, however, the degree to which it could in practice reduce disease spread depends on the unknown role of each particle size in transmission.

Asymptomatic but infected individuals are of special concern, and the particles they would emit from breathing are predominantly bioaerosols. To complicate matters further, different individuals vary in the extent to which they emit bioaerosols while breathing. Because of the concern with spread from asymptomatic individuals, who, unlike symptomatic persons, may be out and about, this rapid expert consultation includes the effects of fabric masks on bioaerosol transmission.

Impact of Mask Design and Fabrication on Performance

Any effects of fabric masks will depend on how and how well they are made. In an unpublished study whose raw data are not currently available, Jayaraman[4] and colleagues examined a range of fabric-based filtration systems, in terms of how well they stopped particles (filtration efficiency) and how much they impeded breathing (differential pressure, Delta-P, the measured pressure drop across the material, which determines the resistance of the material to air flow).[5] The study varied fabric type (woven, woven brushed, knitted, knitted brushed, knitted pile), material type (cotton, polyester, polypropylene, silk), fabric parameters (fabric areal density, yarn linear density, fabric weight), and construction type (number of layers, orientation of the layers). The study found wide variation in filtration efficiency. A mask made from a four-layer woven handkerchief fabric, of a sort that might be found in many homes, had 0.7 percent filtration efficiency for 0.3 micron size particles and a Delta-P of 0.1". Much higher filtration efficiency was observed with filters created specifically for the research from a five-layer woven brushed fabric (35.3 percent of the particles were trapped) and from four layers of polyester knitted cut-pile fabric (50 percent of the particles were trapped with a Delta-P of 0.2").

The greater a mask's breathing resistance, which is reflected in a higher Delta-P, the more difficult it is for users to wear it consistently, and the more likely they are to experience breathing difficulties when they do.[6] Although Jayaraman and colleagues did not measure breathing resistance directly, almost all the masks that they tested would be expected to have breathing resistance within the range of commercial N95 respirators. One mask that used 16 layers of the handkerchief fabric, in order to increase filtration efficiency (63% efficiency with Delta-P of 0.425"), had breathing resistance greater than that of commercial N95 respirators, which would cause great discomfort to many wearers and cause some to pass out.

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[4] Jayaraman, S. *Pandemic Flu – Textile Solutions Pilot: Design and Development of Innovative Medical Masks,* Final Technical Report, Georgia Institute of Technology, Atlanta, Georgia, submitted to CDC, February 14, 2012.

[5] The tests were conducted according to ASTM F2299-3 test method using poly-dispersed sodium chloride aerosol particles with an airflow rate of 30L/min and airflow velocity of 11 cm/s. Aerosol sizes measured: 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, 1 and 2 microns.

[6] 3M™ Health Care Particulate Respirator and Surgical Masks, Healthcare Respirator Brochure, 3M Company, MN.

An additional consideration in the effectiveness of any mask is how well it fits users. [7] Even with the best material, if a mask does not fit, virus-containing particles can escape through creases and gaps between the mask and face. Leakage can also occur if the holding mechanism (e.g., straps, Velcro®) is weak. We found no studies of non-expert individuals' ability to produce properly fitting masks. Nor did we find any studies of the effectiveness of masks produced by professionals, when following instructions available to the general public (e.g., online). Given the current Centers for Disease Control and Prevention (CDC) recommendation to wear cloth face coverings in public settings in areas of significant community-based transmission, additional research should examine the ability of the general public to produce properly fitted fabric masks when following communications and instructions.

Role of the Wearer

The effectiveness of homemade fabric masks will also depend on wearers' behavior. Even if a mask could fit well, its effectiveness still depends on how well wearers put it on and keep it in place. As mentioned, breathing difficulty can impede effective use (e.g., pulling a mask down), as can moisture from wearers' breath. Moisture saturation is inevitable with fabrics available in most homes. Moreover, moisture can trap virus and become a potential contamination source for others, after a mask is removed.

Effectiveness of Homemade Fabric Masks in Protecting Others

Several experimental studies have examined the effects of fabric masks on transmission of droplets of various sizes.

Anfinrud and colleagues[8] shared via email that they used sensitive laser light-scattering procedures to detect droplet emission while people were speaking. The authors found that "a damp homemade cloth facemask" reduced droplet emission to background levels (when users said "Stay Healthy" three times). However, when a fabric is dampened, the yarns can swell over time, potentially altering its filtering performance. That swelling will depend on the fabric: cotton swells readily, synthetics less so. In an unpublished follow-up experiment, Anfinrud and colleagues repeated their study with a variety of dry (not moistened) cloths, including a standard workers dust mask (not certified N95) and a mask rigged from an airline eye covering. They found that all of these masks reduced droplet emission generated by speech to background level. [9]

Bae et al., 2020 evaluated the effectiveness of surgical and cotton masks in filtering SARS–CoV-2.[10] They found that neither kind of mask reduced the dissemination of

[7] Davies and colleagues (2013) noted that, "Although any material may provide a physical barrier to an infection, if as a mask it does not fit well around the nose and mouth, or the material freely allows infectious aerosols to pass through it, then it will be of no benefit."
[8] Anfinrud, P., et al. New England Journal of Medicine, In Press. Could SARS-CoV-2 be transmitted via speech droplets?
[9] Personal communication, Adriaan Bax, National Institutes of Health, 4/4/2020.
[10] Bae, S., et al. 2020. Effectiveness of surgical and cotton masks in blocking sars–cov-2: A controlled comparison in 4 patients. Annals of Internal Medicine.

SARS–CoV-2 from the coughs of four symptomatic patients with COVID-19 to the environment and external mask surface. The study used disposable surgical masks (180 mm × 90 mm, 3 layers [inner surface mixed with polypropylene and polyethylene, polypropylene filter, and polypropylene outer surface], pleated, bulk packaged in cardboard; KM Dental Mask, KM Healthcare Corp) and reusable 100% cotton masks (160 mm × 135 mm, 2 layers, individually packaged in plastic; Seoulsa). The median viral loads of nasopharyngeal and saliva samples from the four participants were 5.66 log copies/mL and 4.00 log copies/mL, respectively. The median viral loads after coughs without a mask, with a surgical mask, and with a cotton mask were similar: 2.56 log copies/mL, 2.42 log copies/mL, and 1.85 log copies/mL, respectively. All swabs from the outer mask surfaces of the masks were positive for SARS–CoV-2, whereas swabs from three out of the four symptomatic patients from the inner mask surfaces were negative. Note that this study focused on symptomatic patients who coughed.

Rengasamy et al. (2010)[11] tested the filtration performance of five common household fabric materials: sweatshirts, T-shirts, towels, scarves and cloth masks (of unknown material) in a laboratory setting. These fabric materials were tested for sprays having both similar and diverse particle sizes (monodisperse and polydisperse). The range of sizes used in the study (.02 – 1 micron) includes that of potential virus-containing droplets.[12] The study projected the particles at face velocities, typical of breathing at rest and during exertion (5.5 and 16.5 cm/s). The test also examined N95 respirator filter media. At the lower velocity, 0.12 percent of particles penetrated the N95 respirator material; at the higher velocity, penetration was less than 5 percent. For the five common household fabric materials, across the tests, penetration ranged from about 40 to 90 percent, indicating a 10-60 percent reduction. The authors concluded that common fabric materials may provide a low level of protection against nanoparticles, including those in the size ranges of virus-containing particles in exhaled breath (.02 – 1 micron). However, Gralton et al. (2011) found particles generated from respiratory activities range from 0.01 up to 500 microns, with a particle size range of 0.05 to 500 microns associated with infection. They stress the need for airborne precautions to be used when at risk of any aerosolised infection, as airborne precautions are considered as a step-up from droplet precautions.

Davies and colleagues (2013)[13] had 21 healthy volunteers make their own facemasks from fresh, unworn cotton t-shirts. This is the only study we found with user-made masks. Participants then coughed into a box, when wearing their own mask, a surgical mask, or no mask. They received no help or guidance from the researcher in making or fitting their masks. The researchers took samples of particles settling onto agar plates and a Casella slit sampler in the box. Under the baseline conditions of no mask, only a small number of colony-forming units (indicative of bacteria) were detected, limiting the

[11] Rengasamy, S., et al. 2010. Simple respiratory protection--evaluation of the filtration performance of cloth masks and common fabric materials against 20-1000 nm size particles. Ann Occup Hyg 54(7):789-798.

[12] According to Gralton et al (2011), particles generated from respiratory activities range from 0.01 up to 500 microns, with a particle size range of 0.05 to 500 microns associated with infection.

[13] Davies, A., et al. 2013. Testing the efficacy of homemade masks: Would they protect in an influenza pandemic? Disaster Med Public Health Prep 7(4):413-418.

opportunity to demonstrate reductions. Still, the investigators reported that both homemade and surgical masks reduced the number of large-sized microorganisms expelled by volunteers, with the surgical mask being more effective.

van der Sande and colleagues (2008)[14] examined the extent to which respirator masks, surgical masks, and tea-cloth masks made by the researchers would reduce tiny (0.02-1.0 micron) particle counts on one side of the mask compared to the other. They used burning candles in a test room to generate particles. Two of the study's three experiments examined the protection afforded the wearer (reduced particle counts inside the masks compared to outside). Although not directly germane to the question of protecting others, the study found a modest degree of protection for the wearer from cloth masks, an intermediate degree from surgical masks and a marked degree with equivalent of N95 masks. For example, among adults, N95 masks provided 25 times the protection of surgical masks and 50 times the protection of cloth masks. The study's third experiment tested the effectiveness of the three masks at reducing emissions from a simulation dummy head that produced uniform "exhalations." It found that cloth masks reduced emitted particles (leakage) by 1/5, surgical masks reduced it by 1/2, and N95-equivalent masks reduced it by 2/3.

MacIntyre et al. (2015)[15] conducted a randomized control trial (RCT) comparing infection rates of 1,607 hospital healthcare workers, wearing cloth (two layers, made of cotton) or medical masks (three layers, made of non-woven material), while performing their normal tasks. Workers who used cloth masks experience much higher rates of influenza-like illness (relative risk = 13.00, 95% CI 1.59 to 100.07). This study measured the protective effect for the wearer, rather than the protection of others from the wearer, and did not include a condition with individuals wearing no masks.

Effect on Users' Risk Behavior

In our rapid review, we found no studies of the effects of wearing masks on users' behavior. Speculatively, for some users, masks could provide a constant reminder of the importance of social distancing, as well as signal its importance to others, strengthening the social norm of social distancing. Conversely, for some users, masks might "crowd out" other precautionary behaviors, giving them a feeling that they have done enough to protect themselves and others. Prior research, conducted in less intense settings, could support either speculation. Focused research could help determine when precautionary behaviors reinforce or displace one another.

It is critically important that any discussion of homemade fabric masks reinforce the central importance of physical distancing and personal hygiene (frequent hand-washing) in reducing spread of infection.

Conclusions

[14] van der Sande, M., et al. 2008. Professional and home-made facemasks reduce exposure to respiratory infections among the general population. PLoS One 3(7):e2618.
[15] MacIntyre, C., et al. 2015. A cluster randomised trial of cloth masks compared with medical masks in healthcare workers. BMJ Open 5(4):e006577.

There are no studies of individuals wearing homemade fabric masks, in the course of their typical activities. Therefore, we have only limited, indirect evidence regarding the effectiveness of such masks for protecting others, when made and worn by the general public on a regular basis. That evidence comes primarily from laboratory studies testing the effectiveness of different materials at capturing particles of different sizes.

The evidence from these laboratory filtration studies suggests that such fabric masks may reduce the transmission of larger respiratory droplets. There is little evidence regarding transmission of small aerosolized particulates of the size potentially exhaled by asymptomatic or presymptomatic individuals with COVID-19. The extent of any protection will depend on how the masks are made and used. It will also depend on how mask use affects users' other precautionary behaviors, including their use of better masks, when those become widely available. Those behavioral effects may undermine or enhance homemade fabric masks' overall effect on public health. The current level of benefit, if any, is not possible to assess.

Research could provide firmer answers by assessing the effectiveness of such fabric masks, as made and used by the general public. That research would have the goals of providing the public with (1) usable instructions on how to make, fit, use, and clean homemade fabric masks; (2) estimates of the protection that such masks afford users and others in different environments (e.g., where the likelihood of contact is higher, like grocery stores, compared to wearing masks all of the time); and (3) effective reinforcement of other precautionary behaviors. That research could provide policy makers with estimates of the net effect of encouraging use of homemade fabric masks on public health, with realistic estimates of how such masks will be made and used, as well as how they will affect other precautionary behaviors of users and others who observe and interact with them.

My colleagues and I hope this input is helpful to you as you continue to guide the nation's response in this ongoing public health crisis.

Respectfully,

Richard Besser, M.D.
Member
Standing Committee on Emerging Infectious Diseases and 21st Century Health Threats

Baruch Fischhoff, Ph.D.
Member
Standing Committee on Emerging Infectious Diseases and 21st Century Health Threats

APPENDIX

Authors and Reviewers of this Rapid Expert Consultation

This rapid expert consultation was prepared by staff of the National Academies of Sciences, Engineering, and Medicine, and members of the National Academies' Standing Committee on Emerging Infectious Diseases and 21st Century Health Threats: Richard Besser, Robert Wood Johnson Foundation; and, Baruch Fischhoff, Carnegie Mellon University. The following subject matter experts also provided input: Sundaresan Jayaraman, Georgia Tech; and Michael Osterholm, University of Minnesota.

Harvey Fineberg, chair of the Standing Committee, approved this document. The following individuals served as reviewers: Ned Calonge, The Colorado Trust; Robert Hornik, University of Pennsylvania; Thomas Inglesby, Johns Hopkins School of Public Health Center for Health Security; and, Grace Lee, Stanford University. Bobbie A. Berkowitz, Columbia University School of Nursing; Susan Curry, University of Iowa; and, Ellen Wright Clayton, Vanderbilt University Medical Center served as arbiters of this review on behalf of the National Academies' Report Review Committee and its Health and Medicine Division.