No. 20A95

In the Supreme Court of the United States

REV. KEVIN ROBINSON AND RABBI YISRAEL A. KNOPFLER,

Applicants,

v.

PHILIP D. MURPHY, ET AL.,

Respondents.

APPENDIX FOR RESPONDENTS – VOLUME III OF IV, PAGES 400-602

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December 3, 2020

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E HIBIT

Evidence mounts that outside is safer when it comes to COVID-19

thehill.com/policy/healthcare/496483-evidence-mounts-that-outside-is-safer-when-it-comes-to-covid-19

Peter Sullivan May 6, 2020

By Peter Sullivan - 05/06/20 05:30 PM EDT

Health experts say people are significantly less likely to get the coronavirus while outside, a fact that could add momentum to calls to reopen beaches and parks closed during the COVID-19 pandemic.

Being outside shouldn't be seen as completely safe, health experts say. People should continue to avoid crowds and maintain six feet of distance from others to keep away from the virus.

But experts are increasingly confident in evidence showing that the coronavirus spreads much more readily indoors than outdoors, a finding that could help guide policymakers seeking to figure out ways to end lockdowns that have shuttered much of the nation's economy.

"Parks, beaches — as long as they're not cheek to jowl, cycling, walking, this is good," said Tom Frieden, the former director of the Centers for Disease Control and Prevention. "Enjoy nature. It's good for us, and it has very low risk of spreading the virus."

Maryland Gov. Larry Hogan (R) on Wednesday said coronavirus figures suggested the state might be able to begin reopening next week. If it does, he said it would include opening state parks and beaches and allowing outdoor gym classes and religious services.

"Studies suggest activities held outdoors as temperatures warm pose lower COVID risk than those done in confined indoor spaces," tweeted Scott Gottlieb, the former Food and Drug Administration commissioner. "As we re-open, states should look to ease rules to allow more recreational, religious, and business activities to occur outside."

Some cities are already considering options that might help local businesses while keeping people safe.

Hartford, Conn., is one of the cities exploring allowing restaurants to expand their outdoor seating options into parking lots or other outdoor spaces.

Vilnius, the capital of Lithuania, has gone further by opening its central square and other outdoor areas to restaurant seating.

"We need creative solutions, and I think things like closing down streets and having some dispersed [seating] from restaurants is a nice creative solution," said Eleanor Murray, a professor at Boston University School of Public Health.

"We can't continue this lockdown indefinitely," she said. "It's just not going to be psychologically or economically feasible."

Gottlieb pointed to a study, which has not yet been peer-reviewed, that examined outbreaks in 320 Chinese cities outside Hubei province, where the coronavirus is believed to have originated, between Jan. 4 and Feb. 11 and found only one outbreak that occurred outdoors.

Experts warned that people are not completely safe outdoors and that it is important to stay six feet away from people outside.

"You don't want to be in a crowd, regardless of where that crowd is," Murray said.

California Gov. Gavin NewsomGavin NewsomCalifornia coronavirus case count tops 600,000 California slams 'inaccurate and outdated beliefs' of parents suing to reopen schools Bass on filling Harris's Senate spot: 'I'll keep all my options open' MORE (D) ordered beaches in Orange County to close last week after they became packed with people during a heat wave.

Murray said that even outside on the beach, people who do not live together should stay six feet apart and that activities such as beach volleyball should be avoided because multiple people touching the same equipment can spread the virus.

That means playgrounds also are a danger, she said.

"While it's great to have parks and beaches, you probably don't want playground equipment open," Murray said.

The virus is harder to transmit outdoors because the droplets that spread it are more easily disturbed or dispersed outside in the elements than in a closed, confined, indoor setting.

"It definitely spreads more indoors than outdoors," said Roger Shapiro, a professor at Harvard University's T.H. Chan School of Public Health. "The virus droplets disperse so rapidly in the wind that they become a nonfactor if you're not really very close to someone outdoors — let's say within six feet."

As people go outside for their daily exercise and pass by one another, experts offered reassurance that simply passing someone for a split second outdoors presents a low risk.

"The virus can't magically teleport," said Amesh Adalja, a senior scholar at the Johns Hopkins University Center for Health Security. "It needs a cough or sneeze or something, singing, talking, spitting. ... It's not magnetism or something like that."

Adalja said some of the decisions around activities such as sitting closer than six feet away from a friend outside on the grass have to do with how much risk someone is personally willing to accept.

“There’s not some kind of black or white answer to all of this stuff,” he said. “People are going to have to make a lot of decisions about what risk tolerance they have.”

Indoor spaces such as barbershops are certainly higher risk, though. There are more shared surfaces that could transmit the virus, such as the barber’s chair. Another danger, especially in the summer, is air conditioning, which can circulate the virus through the air.

“If you're in an indoor space that has the air conditioning blasting ... that air conditioning might be blowing the droplets straight at you,” said Murray, the Boston University professor.

Even outdoors, Adalja said people should be mindful of keeping their distance and washing their hands.

“You can go to the beach, you can go to the park, and it can be safe,” he said. “It’s just you have to be cognizant of the fact that the virus is there.”

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E HIBIT RR

How Safe Are Outdoor Gatherings?

The New York Times

July 5, 2020 Sunday 18:52 EST

Section: WELL; live

Length: 1098 words

Byline: Tara Parker-Pope

Highlight: With the virus raging in many parts of the country, new restrictions have left many wondering about the safety of a backyard barbecue or picnic.

Body

With the virus raging in many parts of the country, new restrictions have left many wondering about the safety of a backyard barbecue or picnic.

Is it still safe to socialize outside?

As the coronavirus continues to rage throughout the country, public health officials are telling us to stay home this holiday weekend. Beaches in Texas, Florida and California are closed. And now some recentbackyard gatherings are being blamed for new cases of Covid-19.

The new restrictions and outbreaks have led to new confusion about the safety of socializing outdoors. But experts say the science hasn't changed: Your risk of catching the virus is much lower outdoors than indoors. If you want to spend time with friends, taking the party outside will reduce your risk of contracting Covid-19.

"Outside is definitely safer," said Erin Bromage, a comparative immunologist and biology professor at the University of Massachusetts, Dartmouth. "But it's the type of interactions you have when you're outside that are important."

A Japanese study of 100 casesfound that the odds of catching the coronavirus are nearly 20 times higher indoors than outdoors. Outdoor gatherings lower risk because wind disperses viral droplets, and sunlight can kill some of the virus. Open spaces prevent the virus from building up in concentrated amounts and being inhaled, which can happen indoors when infected people exhale in a confined space for long stretches of time, said Dr. Julian W. Tang, a virologist at the University of Leicester.

If you socialize outdoors, it's important to keep the guest list small. Socializing with just one additional household is safer than mixing multiple households. Make sure that the rate of Covid-19 in your community is low and falling. It's safest to socialize when the test positivity rate is at5 percent or lower — a level that reduces your chances of inviting an infected person to the party.

Recent clusters of cases have been linked to home gatherings that appear to have broken those rules. After an estimated 100 people gathered for a party in Rockland County, N.Y., public health officials tracked nine cases to the event. In Washington D.C., a June 18 backyard fund-raiser with about two dozen guests made headlines when the host and a few guests were reportedly diagnosed with Covid-19. In Texas, a May 30 surprise party infected 18 family members.

But adding to the confusion about outdoor gatherings is the fact that the continuing protests over police brutality and the killing of George Floyd in Minneapolis have not been associated with spikes in cases. The reason the protests haven't caused a surge may be because protesters were often moving, lowering the risk of spending extended time with an infected person. Many marchers were also wearing masks.

"I can tell you from our own testing in Minnesota, which has been substantial, we have seen no evidence of any kind of measurable impact of protests on cases," said Michael Osterholm, director of the Center for Infectious Disease Research and Policy at the University of Minnesota. "There could have been cases, surely, but it was not a major amplifying event."

Julia Marcus, an infectious disease epidemiologist and assistant professor in the department of population medicine at Harvard Medical School, said the data collected from protesters so far, along with studies suggesting that outdoors is lower risk for transmission, should reassure public health officials about the safety of masked outdoor gatherings and prompt them to open beaches and public outdoor spaces to help people gather more safely during the pandemic.

"Outdoors is what will save us," Dr. Marcus said. "Why can't the message be: 'We understand you want to get together with friends. There are ways to do this safely.' We're just telling them not to gather. That doesn't recognize basic human behavior and basic human needs."

A review of 7,000 cases in China documented only a single instance of outdoor transmission — but it apparently occurred during a long conversation between two friends. One of them had just returned from Wuhan, the center of the outbreak.

If you attend a social event and find yourself in close conversation with someone from outside your household, even outdoors, wear a mask. Keep music levels low so people don't have to shout. (Loud speaking expels more droplets than a quiet voice.) Don't share food or serving utensils.

"I think people hear that it's outdoors and think everything is fine," said Linsey Marr, an engineering professor and aerosol scientist at Virginia Tech. "But it should be outdoors with distancing. If you have an outdoor gathering with a lot of people talking, you stand close. It's loud, so you talk louder."

Limiting the number of partygoers not only lowers your risk of running into someone who has the virus, but small numbers also make it easier to keep track of just a few people and maintain physical distance, said Dr. Asaf Bitton, executive director of Ariadne Labs at Brigham and Women's Hospital and the Harvard T.H. Chan School of Public Health.

Dr. Bitton notes that when a group gets larger, even outdoors, it can affect our overall spatial awareness, including proprioception — which is knowing where our body is in space without relying on visual cues. Add in alcohol, and our ability to keep our distance falls short.

"We also know that alcohol or other drugs and medications can significantly alter all senses, with a particularly large effect on proprioception," Dr. Bitton said.

Dr. Osterholm agreed that people should be aware of the effect alcohol can have on efforts to keep a physical distance.

"One of the problems that happens with parties or events like this if alcohol is involved, even the most well-meaning individual who is trying to stay apart a certain number of feet, it's an unnatural act," he said. "People do come together. That's just human nature."

Even though socializing outdoors is relatively safe, people need to stay aware and vigilant. While it's easy to keep your distance from strangers, it's tougher to stay six feet from people you know, Dr. Tang said.

"It is different when you are interacting with people that you know. I was chatting to my gardener outside earlier this week when I realized that neither of us had masks on and we were getting too close," Dr. Tang said. "So whilst people can be more socially distanced when outdoors, especially amongst strangers, with friends and family and once you start talking to someone at a garden party, people forget themselves, and they get too close."

PHOTO: (PHOTOGRAPH BY Getty Images FOR THE NEW YORK TIMES)

Load-Date: July 14, 2020

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Are outdoor gatherings safe? Here's what experts say.

July 17, 2020

With the United States' coronavirus epidemic resurging, Americans eager to reunite with their friends and families in a safe way are turning toward gathering outside. But some cities recently have linked coronavirus outbreaks to outdoor events, leaving some people to wonder: Are outdoor gatherings safe?

Your top resources for Covid-19 response and resilience

Research suggests outdoor gatherings are safer than indoor events

According to Erin Bromage, a comparative immunologist and biology professor at the **University of Massachusetts-Dartmouth**, some research has shown that "[o]utside is definitely safer" than indoor gatherings when it comes to potentially transmitting or contracting the new coronavirus.

For example, the *New York Times* reports that, in a study that was released preprint and hasn't yet been peer-reviewed, researchers found that the chance of coronavirus transmission occurring indoors was nearly 20 times higher when compared with outdoors.

Further, in another preprint study that hasn't yet been peer-reviewed, researchers reviewed 7,000 coronavirus cases in China and found that just one of those cases stemmed from outdoor transmission, and the transmission likely occurred during a prolonged, face-to-face conversation.

Julian Tang, a virologist at the **University of Leicester**, explained that, generally, the more open a space, the less likely the novel coronavirus can become concentrated in one area in the air and then inhaled by another person, which can result in infection.

But outdoor gatherings still pose risks

But that doesn't mean that outdoor gatherings are without risk, experts say.

For instance, health officials in Rockland County, New York, recently found that nine cases of the novel coronavirus were connected to an outdoor gathering of 100 people. And in Washington, D.C., officials found that a backyard fundraiser with about 24 guests was linked to new cases of coronavirus infection among a few attendees.

Bromage explained that "the type of interactions you have when you're outside" are "important."

"I think people hear that it's outdoors and think everything is fine," said Linsey Marr, an engineering professor and aerosol scientist at Virginia Tech. However, she said, "If you have an outdoor gathering with a lot of people talking, you stand close. It's loud, so you talk louder," and that can increase risk of transmission.

Asaf Bitton, executive director of Ariadne Labs at Brigham and Women's Hospital and the Harvard T.H. Chan School of Public Health, said large gatherings make it difficult to maintain the physical distance needed to protect yourself from potential transmission, even if the event is held outdoors. In addition, inviting more people increases the possibility that someone at the gathering is infected and could transmit the virus, Bitton said.

"Spewing respiratory droplets over a longer distance can occur [outdoors] if someone has a vigorous cough," Krysia Lindan, a clinical epidemiologist at the University of California-San Francisco, noted.

Consuming alcohol at an outdoor event also could be risky, according to Bitton. He noted that alcohol "can significantly alter all senses" and make it even more difficult for people to maintain appropriate physical distance.

"One of the problems that happens with parties or events like this if alcohol is involved, even the most well-meaning individual who is trying to stay apart a certain number of feet, it's an unnatural act," Michael Osterholm, director of the University of Minnesota's Center for Infectious Disease Research and Policy, explained. "People do come together. That's just human nature."

How can you keep outdoor gatherings safe?

Still, there are steps you can take to gather with friends and extended family outdoors while keeping your risk of coronavirus transmission low.

Marr said people gathering outdoors should remember that they should keep physical distance between them and anyone who doesn't live in their household. "It should be outdoors with distancing."

While health experts largely recommended keeping at least six feet of distance between yourself and people who don't live in your household, Joseph Allen, director of the Healthy Buildings program at the Harvard T.H. Chan School of Public Health, said, "10 feet is better."

Experts also suggested not hosting or attending outdoor events where alcohol is served and bringing your own or asking guests to bring their own food, drinks, and dish wear to outdoor gatherings. In addition, some experts recommend that you wear a mask when in close conversation with others, even when outdoors, and that you only gather with others who are practicing physical distancing and other precautions to protect themselves from the coronavirus.

Anthony Fauci, director of the National Institute of Allergy and Infectious Diseases, said "on the rare occasion" that he and his family "have people over, we have them out on the deck, six feet apart, and we never have more than two people, and they are people who themselves are" practicing social distancing. He added, "We wear masks, unless we are eating. We don't share anything. There are no common bowls. Each person has his or her own receptacle. Some people even bring their own glasses. We always do takeout and I tell the takeout people that I want the food in four separate plastic containers, so no one has to touch anyone else's food."

Elizabeth Connick, chief of the infectious diseases division and a professor of medicine and immunobiology at the University of Arizona, said she's "had a few people over to dinner and [they] eat outside." She explained, "I don't have many people over. The people I have over have been quarantining. We don't wear masks. We sit outside at a good distance. I think if you are outside at a good distance the risk is very small. I invite over people who are very circumspect in their behavior. No one comes over to my house who goes to restaurants or bars."

You also should keep your community's infection rate in mind when determining whether to host or attend an outdoor gathering, because as your area's infection rate increases, so does your risk of coming into contact with someone who's infected with the novel coronavirus.

According to the *Times*, people should avoid socializing with anyone who doesn't live in their household when the positivity rate for coronavirus tests in their areas exceeds 5%.

However, Lindan said the resurgence of America's coronavirus epidemic over the past couple weeks has gotten to a level at which "no one should be out without a mask, and everyone should be trying to distance as much as feasible, even if retail (and other businesses) are opening up."

Overall, Lindan explained, "Nothing has changed about precautions to prevent yourself and others from becoming infected." She said, "Wear a mask at all times that you are out ... which ideally would occur at least six feet away from others in your 'safe' group. Clean/disinfect your hands," and "[b]eing outside for activities, for seeing friends, and for eating is better than inside" (Parker-Pope, *New York Times*, 7/3; Courage, *Vox*, 7/11; Reddy, *Wall Street Journal*, 6/15; Cimons, *Washington Post*, 7/3).

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E HIBIT TT

CDC calls on Americans to wear masks to prevent COVID-19 spread

Centers for Disease Control and Prevention Documents and Publications

July 14, 2020

Section: PRESS RELEASE, MEDIA STATEMENTS, PUBLIC DOCUMENTS

Length: 982 words

Body

CDC calls on Americans to wear masks to prevent COVID-19 spread

JAMA editorial reviews latest science, while case study shows masks prevented COVID spread

Tuesday, July 14, 2020

Contact: Media Relations (https://www.cdc.gov/media)

(404) 639-3286

Americans are increasingly adopting the use of cloth face masks to slow the spread of COVID-19, and the latest science may convince even more to do so.

In an editorial published today in the Journal of the American Medical Association (JAMA), CDC reviewed the latest science and affirms that cloth face coverings are a critical tool in the fight against COVID-19 that could reduce the spread of the disease, particularly when used universally within communities. There is increasing evidence that cloth face coverings help prevent people who have COVID-19 from spreading the virus to others.

"We are not defenseless against COVID-19," said CDC Director Dr. Robert R. Redfield. "Cloth face coverings are one of the most powerful weapons we have to slow and stop the spread of the virus - particularly when used universally within a community setting. All Americans have a responsibility to protect themselves, their families, and their communities."

This review included two case studies out today, one from JAMA, showing that adherence to universal masking policies reduced SARS-CoV-2 transmission within a Boston hospital system, and one from CDC's

Morbidity and Mortality Weekly Report (MMWR), showing that wearing a mask prevented the spread of infection from two hair stylists to their customers in Missouri.

Additional data in today's MMWR showed that immediately after the White House Coronavirus Task Force and CDC advised Americans to wear cloth face coverings when leaving home, the proportion of U.S. adults who chose to do so increased, with 3 in 4 reporting they had adopted the recommendation in a national internet survey.

The results of the Missouri case study provide further evidence on the benefits of wearing a cloth face covering. The investigation focused on two hair stylists -- infected with and having symptoms of COVID-19 -- whose salon policy followed a local ordinance requiring cloth face coverings for all employees and patrons. The investigators found that none of the stylists' 139 clients or secondary contacts became ill, and all 67 clients who volunteered to be tested showed no sign of infection.

The finding adds to a growing body of evidence that cloth face coverings provide source control - that is, they help prevent the person wearing the mask from spreading COVID-19 to others. The main protection individuals gain from masking occurs when others in their communities also wear face coverings.

COVID-19 prevention in a Missouri hair salon

When two stylists at a Missouri hair salon tested positive for the virus that causes COVID-19, researchers from CoxHealth hospitals, Washington University, the University of Kansas, and the Springfield-Greene County Health Department worked together to trace contacts, investigate the cases, and publish their findings in the MMWR.

One of the stylists developed respiratory symptoms but continued to see clients for eight days. The other, who apparently became infected from her co-worker, also developed respiratory symptoms and continued to see clients for four days.

The salon in which they worked had a policy requiring both stylists and their clients to wear face coverings, consistent with the local government ordinance. Both stylists wore double-layered cloth face coverings or surgical masks when seeing clients. The median appointment time was 15 minutes and ranged from 15 to 45 minutes. More than 98% of clients wore a face covering--47% wore cloth face coverings, 46% wore surgical masks, and about 5% wore N-95 respirators.

When customers were asked whether they had been ill with any respiratory symptoms in the 90 days preceding their appointment, 87

(84%) reported that they had not. None of the interviewed customers developed symptoms of illness. Among 67 (48%) customers who volunteered to be tested, all 67 tested negative for the virus that causes COVID-19. Several family members of one of the stylist's subsequently developed symptoms and received a diagnosis of COVID-19.

Survey: Acceptance of face-mask guidance increased

CDC analyzed data from an internet survey of a national sample of 503 adults during April 7-9 and found that about 62% said they would follow the newly announced recommendations to wear a face mask when outside the home. A repeat survey during May 11-13 showed that the percentage of adults endorsing face mask wearing increased to more than 76%.

The increase was driven largely by a significant jump in approval by white, non-Hispanic adults, from 54% to 75%. Approval among Black, non-Hispanic adults went up from 74% to 82%, and remained stable among Hispanic/Latino adults at 76% and 77%.

There was also a large increase in face-mask approval among respondents in the Midwest, from 44% to 74%. Approval was greatest in the Northeast, going from 77% to 87%.

Resources:

- CDC's Information on Cloth Face Coverings: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/diy-cloth-face-coverings.html

- CDC Editorial in JAMA: Brooks JT, Butler JC, Redfield RR. Time for universal masking and prevention of transmission of SARS-CoV-2. JAMA. Published online July 14, 2020. doi:10.1001/jama.2020.13107 https://jamanetwork.com/journals/jama/fullarticle/10.1001/jama.2020.13107

- MMWR Article: No Transmission of Symptomatic SARS-CoV-2 After Significant Exposure With Universal Face Mask Use at a Hair Salon - Springfield, Missouri, May 2020 https://www.cdc.gov/mmwr/volumes/69/wr/mm6928e2.htm?s_cid=mm6928e2_w

MMWR Article: Factors Associated with Cloth Face Coverings Use during the COVID-19 Pandemic -- United States, April and May 2020 https://www.cdc.gov/mmwr/volumes/69/wr/mm6928e3.htm?s_cid=mm6928e3_w

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CDC calls on Americans to wear masks to prevent COVID-19 spread

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EUROPEAN RESPIRATORY *journal*

FLAGSHIP SCIENTIFIC JOURNAL OF ERS

Early View

Correspondence

Universal use of face masks for success against COVID-19: evidence and implications for prevention policies

Susanna Esposito, Nicola Principi, Chi Chi Leung, Giovanni Battista Migliori

Please cite this article as: Esposito S, Principi N, Leung CC, *et al*. Universal use of face masks for success against COVID-19: evidence and implications for prevention policies. *Eur Respir J* 2020; in press (https://doi.org/10.1183/13993003.01260-2020).

This manuscript has recently been accepted for publication in the *European Respiratory Journal*. It is published here in its accepted form prior to copyediting and typesetting by our production team. After these production processes are complete and the authors have approved the resulting proofs, the article will move to the latest issue of the ERJ online.

Universal use of face masks for success against COVID-19: evidence and implications for prevention policies

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Take home message (max 256 characters, including spaces): Cloth masks are a simple, economic and sustainable alternative to surgical mask as a means of source control of SARS-CoV-2 for general community.

Running title: Face masks for success against COVID-19.

Key-words: COVID-19; facial mask; surgical mask; prevention, airborne diseases

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Text (word count): 837

Dear Editor,

A hot debate is taking place on the use of face masks (including cloth and surgical) as a prevention tool in the community vis-à-vis the recent World Health Organization (WHO) recommendations. To shed light on this important topic we reviewed relevant literature focused on the key words „infection control", „prevention", „masks", „respirators", „viral infections" and „COVID-19" without time restrictions to identify a minimum set of references from an electronic database (PUBMED), existing guidelines, viral diseases, airborne diseases, and grey literature.

The core findings of the references identified are summarised in Table 1.

According to the WHO report from February 2020 (https://www.who.int/docs/default-source/coronaviruse/who-chinajoint-mission-on-covid-19-final-report.pdf.), the proportion of truly asymptomatic carriers of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection was relatively small and not a major driver of virus circulation, infection transmission, and new disease development. However, in blanket testing of an isolated village of approximately 3,000 people in northern Italy, 50%-75% of people with positive pharyngeal molecular tests were totally asymptomatic [1]. This finding was echoed by a more recent daily surveillance report from China, where all people arriving from overseas were rigorously tested [2]: among 166 persons with newly identified infections, 78% were asymptomatic. Although the infective dose associated with transmission is not known, the viral load in the respiratory tract in an asymptomatic patient has been reported to be similar to patients with symptoms [3], and transmission of SARS-CoV-2 infection from an asymptomatic contact has also been described [4].

Until some weeks ago, it was thought that the virus could be transmitted only by droplets that are coughed or sneezed out or by contaminated fomites, with differences according to the initial load and surface characteristics [5]. Airborne transmission of SARS-CoV-2 was considered possible only when care procedures generating aerosols (e.g. intubation, bronchoscopy, and positive-pressure ventilation) are performed [6]. However, other studies seem to indicate the opposite, i.e., the virus can be present in exhaled air produced by talking and breathing [6]. Moreover, a potential role of aerosols in virus diffusion was evident in a complex laboratory study. Aerosols containing a viral load quite similar to that observed in human respiratory samples were created to generate an aerosolized environment. SARS-CoV-2 was detected up to 3 hours after the start of the study [7]. Although these findings were not considered fully convincing by some authors [5], they

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deserve attention and require further studies to establish whether and when airborne transmission of SARS-CoV-2 truly occurs and how it can be reduced.

It is well known that surgical masks can prevent the inhalation of large droplets and sprays but have limited ability to filter submicron-sized airborne particles [8,9]. As SARS-CoV-2 is also embedded in aerosols <5 μm in diameter, it cannot be determined whether they are always effective. However, mask wearing by patients with pulmonary tuberculosis (an airborne infectious disease) has been shown to reduce infectivity to guinea pigs by 56% [9,10]. The surgical mask has also been shown to intercept other human coronaviruses during coughing [11]. A meta-analysis of randomized controlled trials also showed that surgical masks and N95 respirators were similarly effective in preventing influenza-like illness and laboratory-confirmed influenza among healthcare workers [12]. Similar results were obtained in a case-control study comparing the protective effect of surgical masks and N95 respirators against SARS among healthcare workers in five Hong Kong hospitals [13].

Controlling a respiratory infection at source by a face mask is a well-established strategy. For example, symptomatic patients with cough or sneezing are generally advised to put on a face mask, and this applies equally to patients with pulmonary tuberculosis (airborne transmission) and influenza (predominantly droplet-transmitted). With the large number of asymptomatic patients unware of their own infection [1,2], the comparable viral load in their upper respiratory tract [3], droplet and aerosol dispersion even during talking and breathing [6], and prolonged viral viability outside our body [7], we strongly advocate universal use of face mask as a means of source control in public places during the COVID-19 pandemic. Extreme forms of social distancing is not sustainable, and complete lockdown of cities or even whole countries is extremely devastating to the economy. Universal masking in public complements social distancing and hand hygiene in containing or slowing down the otherwise exponential growth of the pandemic. Universal masking protects against cross-transmission through unavoidable person-to-person contact during the lockdown and reduces the risk for resurgence during relaxation of social distancing measures on reopening.

A high degree of compliance will maximize the impact of universal masking in public. The global shortage of surgical masks and N95 respirators is a serious concern. In line with the recent recommedation by US CDC for healthy people to wear a cloth face cover in public [14], we strongly support the use of cloth masks as a simple, economic and sustainable alternative to surgical mask as a means of source control for general community use, so that disposable surgical masks and N95 respirators can be reserved for use in health care facilities. Such intervention is likely to be life-saving in many resource limited settings.

Author contributions

S.E. and N.P. co-wrote the manuscript. GBM and CCL wrote sections of the manuscript, edited the text for major intellectual components and designed the Table. All authors approved the text.

Conflict of interest

Authors declare no competing interests.

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Table 1. Main studies on severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission.

Authors	Setting	Study	Main findings and comments
Day M. BMJ 2020;368:m1165. [1]	Vo" Euganeo, Italy	RNA testing of the entire village population (3,000 inhabitants)	50-75% of infected individuals asymptomatic, representing "a formidable source" of contagion. Isolation of asymptomatic individuals essential for controlling virus spread and epidemic seriousness
Day M. BMJ 2020; 369:m1375. [2]	China	Screening on overseas arrivals	130 of 166 new infections (78%) identified in the 24 hours to the afternoon of Wednesday 1 April 2020 were asymptomatic. Asymptomatic infections would not be able to cause another major outbreak of COVID-19 if such individuals were kept in isolation.
Zou L et al. N Engl J Med 2020; 382: 1177–79. [3]	Zhuhai, Guangdong, China	Monitoring SARS-CoV-2 viral loads in upper respiratory specimens of 18 patients	Higher viral loads were detected soon after symptom onset and viral load in an asymptomatic patient was similar to that in the symptomatic patients.
Rhote C. et al. N Engl J Med 2020;382:970-971. [4]	Munich, Germany	Report of transmission of COVID-19 from an asymptomatic individual to 4 contacts	The fact that asymptomatic persons are potential sources of COVID-19 infection may warrant a reassessment of transmission dynamics of the current outbreak.
World Health Organization. Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations . [5]	Global	Precaution recommendations	The routes of COVID-19 transmission are via droplet, fomites and airborne transmission of droplet nuclei (<5μm), with less evidence for intestine transmission. WHO continues to recommend droplet and contact precautions and not airborne precautions.
Lewis D. Is the coronavirus airborne? Experts can"t agree. Nature 2020. [6]		Reporting of different viewpoints	Arguments in favour and against airborne transmission and related prevention are discussed.
van Doremalen N. et al. N Engl J Med 2020. [7]	USA	Stability of SARS-CoV-2 and SARS-CoV-1 in aerosols and on various surfaces was evaluated and their decay rates estimated using a Bayesian regression model	Aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days.
University of Maryland. ScienceDaily, 3 April 2020. [8]	USA		Wearing surgical masks in public could help slow COVID-19 pandemic's advance: masks may limit the spread diseases including influenza, rhinoviruses and coronaviruses.
Migliori GB, et al. Eur Respir J 2019; 53(6). [9]	Europe	WHO Consensus document	The core components of infection control are discussed, together with precautions to prevent unnecessary admissions, with focus on tuberculosis. The importance of personal protection (respirators to protect health care staff, other patients and visitors and surgical masks for infectious patients) is discussed.

Dharmadhikari AS. et al. Am J Respir Crit Care Med 2012; 185(10): 1104–1109. [10]	South Africa	17 MDR-TB patients wore face masks on alternate days. Ward air was exhausted to two identical chambers, each housing 90 guinea pigs breathing ward air either when patients wore surgical face masks (intervention group) or when patients did not wear masks (control group).	Sixty-nine of 90 control guinea pigs (76.6%) became infected, compared with 36 of 90 intervention guinea pigs (40%) representing a 56% (95% CI, 33–70.5%) decreased risk of TB transmission when patients used masks. Surgical face masks on patients with MDR-TB significantly reduced transmission and offer an adjunct measure for reducing TB transmission from infectious patients.
Leung NHL et al. Nature Medicine 2020. [11]	Hong Kong	Quantification of the amount of respiratory virus in exhaled breath of participants with medically attended ARIs and determination of the potential efficacy of surgical face masks to prevent respiratory virus transmission	246 patients were studied. Surgical face masks significantly reduced detection of influenza virus RNA in respiratory droplets and coronavirus RNA in aerosols, with a trend toward reduced detection of coronavirus RNA in respiratory droplets. The results indicate that surgical face masks could prevent transmission of human coronaviruses and influenza viruses from symptomatic individuals.
Long Y. J Evid Based Med 2020. [12]	China	Systematic Review and meta-analysis on the effectiveness of N95 respirators versus surgical masks to prevent influenza	The use of N95 respirators compared with surgical masks is not associated with a lower risk of laboratory-confirmed influenza. It suggests that N95 respirators should not be recommended for general public and non high-risk medical staff those are not in close contact with influenza patients or suspected patients.
Seto WH. Lancet 2003;361:1519-1520. [13]	Hong Kong	Case-control study in 5 hospitals	241 non-infected and 13 infected staff were surveyed about use of mask, gloves, gowns, and hand-washing. 69 staff reporting use of all four measures were not infected, while all infected staff omitted at least one measure (p=0.0224). Fewer staff who wore masks (p=0.0001), gowns (p=0.006), and washed their hands (p=0.047) were infected compared with those who did not; stepwise logistic regression was significant only for masks (p=0.011). Practice of droplets precaution and contact precaution is adequate in significantly reducing the risk of infection after exposures to patients with SARS. The protective role of masks suggests that in hospitals, infection is transmitted by droplets.
Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19). How to Protect Yourself & Others.[14]	USA	Guidance to the public	Core recommendations are: 1. Clean your hands often; 2. Avoid close contact; 3. Cover your mouth and nose with a cloth cover when around others; 4. Cover cough and sneezes; 5. Clean and disinfect.

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E HIBIT VV

Letters

RESEARCH LETTER

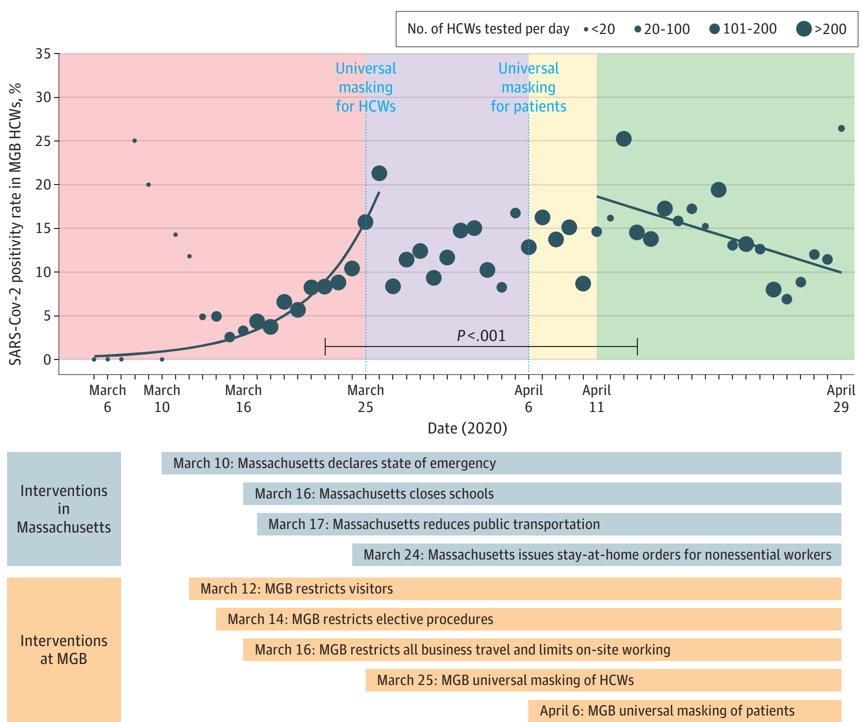
Association Between Universal Masking in a Health Care System and SARS-CoV-2 Positivity Among Health Care Workers

The coronavirus disease 2019 (COVID-19) pandemic, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has severely affected health care workers (HCWs).[1] As a result, hospital systems began testing HCWs[2] and implementing infection control measures to mitigate workforce depletion and prevent disease spread.[3] Mass General Brigham (MGB) is the largest health care system in Massachusetts, with 12 hospitals and more than 75 000 employees. In March 2020, MGB implemented a multipronged infection reduction strategy involving systematic testing of symptomatic HCWs and universal masking of all HCWs and patients with surgical masks.[4] This study assessed the association of hospital masking policies with the SARS-CoV-2 infection rate among HCWs.

+ Editorial

Methods | The institutional review board of MGB approved the study and waived informed consent. Using electronic medical records, we identified HCWs providing direct and indirect patient care who were tested for SARS-CoV-2 with reverse transcriptase-polymerase chain reaction between March 1 and April 30, 2020. The primary criterion for testing HCWs in our health care system was having symptoms consistent with SARS-CoV-2 infection. Information on the job description of each HCW was obtained by linking their record to the MGB Occupational Health Services and Human Resources databases.

Figure. Temporal Trend in Percentage Positivity of SARS-CoV-2 Testing Among HCWs



HCW indicates health care worker; MGB, Mass General Brigham; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2. All dates given are for the year 2020. The size of each data marker is proportional to the total number of SARS-CoV-2 tests performed each day over the time of the study period (x-axis), while the position of each data marker along the y-axis shows the percentage of daily test results that were positive among HCWs. The horizontal bars below the x-axis represent the timing of key interventions implemented in the state of Massachusetts and at MGB. The dotted lines represent the implementation dates of hospital policies. The study period is divided into 3 phases: a preintervention period before implementation of universal masking of HCWs (pink), which includes March 26, the day after implementation of universal masking for HCWs, to account for HCWs who became symptomatic after business hours on March 25 and were tested on March 26; a transition period until implementation of universal masking of patients (purple) plus an additional lag period (yellow); and the intervention period (green). For the preintervention and intervention periods, daily tests were fitted by weighted nonlinear regression (curves). The change in overall slope was compared between the 2 curves to determine any statistically significant changes in trend (as shown by the *P* value).

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We identified 3 phases during the study period: a preintervention period before implementation of universal masking of HCWs (March 1-24, 2020); a transition period until implementation of universal masking of patients (March 25-April 5, 2020) plus an additional lag period to allow for manifestations of symptoms (April 6-10, 2020), as previously defined[5]; and an intervention period (April 11-30, 2020). Positivity rates included the first positive test result for all HCWs in the numerator and HCWs who never tested positive plus those who tested positive that day in the denominator. For each HCW, any tests subsequent to their first positive test result were excluded. Using weighted nonlinear regression, we fit the best curve for the preintervention and intervention periods (based on R^2 value). The number of daily tests was used as the weight such that days with more tests had more weight in determining the curve. The overall slope of each period was calculated using linear regression to estimate the mean trend, regardless of curve shape. The change in overall slope between the preintervention and intervention periods was compared to determine any statistically significant change in mean trend, using a 2-sided $\alpha = .05$. The analysis was conducted using R version 4.0 (R Foundation).

Results | Of 9850 tested HCWs, 1271 (12.9%) had positive results for SARS-CoV-2 (median age, 39 years; 73% female; 7.4% physicians or trainees, 26.5% nurses or physician assistants, 17.8% technologists or nursing support, and 48.3% other). During the preintervention period, the SARS-CoV-2 positivity rate increased exponentially from 0% to 21.32%, with a weighted mean increase of 1.16% per day and a case doubling time of 3.6 days (95% CI, 3.0-4.5 days). During the intervention period, the positivity rate decreased linearly from 14.65% to 11.46%, with a weighted mean decline of 0.49% per day and a net slope change of 1.65% (95% CI, 1.13%-2.15%; $P < .001$) more decline per day compared with the preintervention period (**Figure**).

Discussion | Universal masking at MGB was associated with a significantly lower rate of SARS-CoV-2 positivity among HCWs. This association may be related to a decrease in transmission between patients and HCWs and among HCWs. The decrease in HCW infections could be confounded by other interventions inside and outside of the health care system (Figure), such as restrictions on elective procedures, social distancing measures, and increased masking in public spaces, which are limitations of this study. Despite these local and statewide measures, the case number continued to increase in Massachusetts throughout the study period,[6] suggesting that the decrease in the SARS-CoV-2 positivity rate in MGB HCWs took place before the decrease in the general public. Randomized trials of universal masking of HCWs during a pandemic are likely not feasible. Nonetheless, these results support universal masking as part of a multipronged infection reduction strategy in health care settings.

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Acquisition, analysis, or interpretation of data: All authors.
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Morbidity and Mortality Weekly Report

Absence of Apparent Transmission of SARS-CoV-2 from Two Stylists After Exposure at a Hair Salon with a Universal Face Covering Policy — Springfield, Missouri, May 2020

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On July 14, 2020, this report was posted as an MMWR *Early Release on the* MMWR *website (https://www.cdc.gov/mmwr).*

On May 12, 2020 (day 0), a hair stylist at salon A in Springfield, Missouri (stylist A), developed respiratory symptoms and continued working with clients until day 8, when the stylist received a positive test result for SARS-CoV-2, the virus that causes coronavirus disease 2019 (COVID-19). A second hair stylist (stylist B), who had been exposed to stylist A, developed respiratory symptoms on May 15, 2020 (day 3), and worked with clients at salon A until day 8 before seeking testing for SARS-CoV-2, which returned a positive result on day 10. A total of 139 clients were directly serviced by stylists A and B from the time they developed symptoms until they took leave from work. Stylists A and B and the 139 clients followed the City of Springfield ordinance* and salon A policy recommending the use of face coverings (i.e., surgical masks, N95 respirators,† or cloth face coverings) for both stylists and clients during their interactions. Other stylists at salon A who worked closely with stylists A and B were identified, quarantined, and monitored daily for 14 days after their last exposure to stylists A or B. None of these stylists reported COVID-19 symptoms. After stylist B received a positive test result on day 10, salon A closed for 3 days to disinfect frequently touched and contaminated areas. After public health contact tracings and 2 weeks of follow-up, no COVID-19 symptoms were identified among the 139 exposed clients or their secondary contacts. The citywide ordinance and company policy might have played a role in preventing spread of SARS-CoV-2 during these exposures. These findings support the role of source control in preventing transmission and can inform the development of public health policy during the COVID-19 pandemic. As stay-at-home orders are lifted, professional and social interactions in the community will present more opportunities for spread of SARS-CoV-2. Broader implementation of masking policies could mitigate the spread of infection in the general population.

Stylist A worked from day 0 to day 8 with COVID-19 symptoms before receiving a diagnosis of COVID-19 by polymerase chain reaction (PCR) testing. Although self-isolation was recommended after testing on day 6, stylist A continued to work until the test returned a positive result, at which time stylist A was excluded from work by salon A. On day 3, after working with stylist A, stylist B developed respiratory symptoms. During Stylist A's symptomatic period, the two stylists interacted while neither was masked during intervals between clients. Stylist B worked from day 3 to day 8 while symptomatic before self-isolating and seeking PCR testing, which returned a positive result for SARS-CoV-2 on day 10. Stylist A worked with clients for 8 days while symptomatic, as did stylist B for 5 days. During all interactions with clients at salon A, stylist A wore a double-layered cotton face covering, and stylist B wore a double-layered cotton face covering or a surgical mask.

The Greene County Health Department (Missouri) conducted contact tracing for all 139 exposed clients back to the dates that stylists A and B first developed symptoms. The 139 clients were monitored after their last exposure at salon A. Clients were asked to self-quarantine for 14 days and were called or sent daily text messages to inquire about any symptoms; none reported signs or symptoms of COVID-19. Testing was offered to all clients 5 days after exposure, or as soon as possible for those exposed >5 days before contact tracing began. Overall, 67 (48.2%) clients volunteered to be tested, and 72 (51.8%) refused; all 67 nasopharyngeal swab specimens tested negative for SARS-CoV-2 by PCR. Telephone interviews were attempted 1 month after initial contact tracings to collect supplementary information. Among the 139 exposed clients, the Greene County Health Department interviewed 104 (74.8%) persons.

Among the 139 clients, the mean age was 52 years (range = 21–93 years); 79 clients (56.8%) were male (Table 1). Salon appointments ranged from 15 to 45 minutes in length (median = 15 minutes; mean = 19.5 minutes). Among the 104 interviewed clients, 102 (98.1%) reported wearing face coverings for their entire appointment, and two (1.9%) reported wearing face coverings part of the time (Table 2). Types of face covering used by clients varied; 49 (47.1%) wore cloth face coverings, 48 (46.1%) wore surgical masks, five (4.8%) wore N95 respirators, and two (1.9%) did not know what kind of face covering they wore. Overall, 101 (97.1%) interviewed clients reported that their stylist wore a face covering for the entire appointment; three did not know. When asked about the type of face coverings worn by the stylists, 64 (61.5%) reported that their stylist wore a cloth face covering (39; 37.5%) or surgical mask

* Springfield, Missouri, city ordinance went into effect May 6, 2020, restricted seating in waiting areas to 25% of normal capacity and recommended social distancing and use of face coverings for employees and clients when social distancing was not or could not be followed. https://www.springfieldmo.gov/5140/Masks-and-Face-Coverings.

† Particulate-filtering facepiece respirators that filter ≥95% of airborne particles (https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/n95list1.html).

Summary

What is already known about this topic?

Consistent and correct use of cloth face coverings is recommended to reduce the spread of SARS-CoV-2.

What is added by this report?

Among 139 clients exposed to two symptomatic hair stylists with confirmed COVID-19 while both the stylists and the clients wore face masks, no symptomatic secondary cases were reported; among 67 clients tested for SARS-CoV-2, all test results were negative. Adherence to the community's and company's face-covering policy likely mitigated spread of SARS-CoV-2.

What are the implications for public health practice?

As stay-at-home orders are lifted, professional and social interactions in the community will present more opportunities for spread of SARS-CoV-2. Broader implementation of face covering policies could mitigate the spread of infection in the general population.

(25; 24.0%); 40 (38.5%) clients did not know or remember the type of face covering worn by stylists. When asked whether they had experienced respiratory symptoms in the 90 days preceding their appointment, 87 (83.7%) clients reported that they had not. Of those who did report previous symptoms, none reported testing for or diagnosis of COVID-19.

Six close contacts of stylists A and B outside of salon A were identified: four of stylist A and two of stylist B. All four of stylist A's contacts later developed symptoms and had positive PCR test results for SARS-CoV-2. These contacts were stylist A's cohabitating husband and her daughter, son-in-law, and their roommate, all of whom lived together in another household. None of stylist B's contacts became symptomatic.

Discussion

SARS-CoV-2 is spread mainly between persons in close proximity to one another (i.e., within 6 feet), and the more closely a person interacts with an infected person and the longer the interaction, the higher the risk for transmission (*1*). At salon A in Springfield, Missouri, two stylists with COVID-19 symptoms worked closely with 139 clients before receiving diagnoses of COVID-19, and none of their clients developed COVID-19 symptoms. Both stylists A and B, and 98% of the interviewed clients followed posted company policy and the Springfield city ordinance requiring face coverings by employees and clients in businesses providing personal care services. The citywide ordinance reduced maximum building waiting area seating to 25% of normal capacity and recommended the use of face coverings at indoor and outdoor public places where physical distancing was not possible. Both company and city policies were likely important factors in preventing the spread of SARS-CoV-2 during these interactions

TABLE 1. Characteristics* of clients (N = 139) who visited hair salon A and were exposed to stylists A and B with COVID-19 —Springfield, Missouri, May 2020

Characteristic	Value
Demographic characteristic	
Male, no. (%)	79 (56.8)
Age, yrs. mean (range)	52 (21–93)
Encounter information	
Appointment date range	May 12–20 (days 0–8†)
Exposure to stylist A, no. (%)	84 (60.4)
Exposure to stylist B, no. (%)	55 (39.6)
Appointment duration, mins, median (range)	15 (15–45)
Client testing	
Clients tested, no. (%)	67 (48.2)
Negative tests, no. (%)§	67 (100)

Abbreviation: COVID-19 = coronavirus disease 2019.
* All interviews were conducted via telephone by the Greene County Health Department.
† After onset of symptoms in stylist A.
§ Among those tested.

between clients and stylists. These results support the use of face coverings in places open to the public, especially when social distancing is not possible, to reduce spread of SARS-CoV-2.

Although SARS-CoV-2 is spread largely through respiratory droplets when an ill person coughs or sneezes (*1*), data suggest that viral shedding starts during the 2-to-3-day period before symptom onset, when viral loads are at their highest (*2*). Although the rate of transmission of SARS-CoV-2 from presymptomatic patients (those who have not yet developed symptoms) and asymptomatic persons (those who do not develop symptoms) is unclear, these persons likely contribute to the spread of SARS-CoV-2 (*3*). With the potential for presymptomatic and asymptomatic transmission, widespread adoption of policies requiring face coverings in public settings should be considered to reduce the impact and magnitude of additional waves of COVID-19.

Previous studies show that both surgical masks and homemade cloth face coverings can reduce the aerosolization of virus into the air and onto surfaces (*4*,*5*). Although no studies have examined SARS-CoV-2 transmission directly, data from previous epidemics (*6*,*7*) support the use of universal face coverings as a policy to reduce the spread of SARS-CoV-2, as does observational data for COVID-19 in an analysis of 194 countries that found a negative association between duration of a face mask or respirator policy and per-capita coronavirus-related mortality; in countries that did not recommend face masks and respirators, the per-capita coronavirus-related mortality increased each week by 54.3% after the index case, compared with 8.0% in those countries with masking policies (CT Leffler, Virginia Commonwealth University, unpublished data, 2020).§ Similar outcomes have been observed for other respiratory virus outbreaks, including the 2002–04 outbreak of Severe Acute Respiratory Syndrome

§ https://doi.org/10.1101/2020.05.22.20109231.

TABLE 2. Hair salon clients' (N = 104) responses to interview questions* about their interactions with two stylists with COVID-19 during salon appointments — Springfield, Missouri, May 12–20, 2020

Interview question	Response	No. (%)
Did you wear a face covering?	Yes, for the entire appointment	102 (98.1)
	Yes, for part of the appointment	2 (1.9)
	No, not at all	0 (—)
	Did not know	0 (—)
What type of face covering did you wear?	Cloth face covering	49 (47.1)
	Surgical mask	48 (46.1)
	N95 respirator†	5 (4.8)
	Did not know	2 (1.9)
	Did not answer question	0 (—)
Did the stylist wear a face covering?	Yes, for the entire appointment	101 (97.1)
	Yes, for part of the appointment	0 (—)
	No, not at all	0 (—)
	Did not know	3 (2.9)
What type of face covering did the stylist wear?	Cloth face covering	39 (37.5)
	Surgical mask	25 (24.0)
	N95 respirator	0 (—)
	Did not know	35 (33.7)
	Did not answer question	5 (4.8)
Did you have a respiratory illness in the past 90 days?	Yes	7 (6.7)
	No	87 (83.7)
	Did not know	1 (1.0)
	Did not answer the question	9 (8.7)

Abbreviation: COVID-19 = coronavirus disease 2019.
* All interviews were conducted via telephone by the Greene County Health Department.
† Particulate-filtering facepiece respirators that filter ≥95% of airborne particles (https://www.cdc.gov/niosh/npptl/topics/respirators/disp_part/n95list1.html).

(SARS) (*6*) and the 2007–08 influenza season (*7*). A systematic review on the efficacy of face coverings against respiratory viruses analyzed 19 randomized trials and concluded that use of face masks and respirators appeared to be protective in both health care and community settings (*8*).

The findings in this report are subject to at least four limitations. First, whereas the health department monitored all exposed clients for signs and symptoms of COVID-19, and no clients developed symptoms, only a subset was tested; thus, asymptomatic clients could have been missed. Similarly, with a viral incubation period of 2–14 days, any COVID-19 PCR tests obtained from clients too early in their course of infection could return false-negative results. To help mitigate this possibility, all exposed clients were offered testing on day 5 and were contacted daily to monitor for symptoms until day 14. Second, although the health department obtained supplementary data, no information was collected regarding underlying medical conditions or use of other personal protective measures, such as gloves and hand hygiene, which could have influenced risk for infection. Third, viral shedding is at its highest during the 2 to 3 days before symptom onset; any clients who interacted with the stylists before they became symptomatic were not recruited for contact tracing. Finally, the mode of interaction between stylist and client might have limited the potential for exposure to the virus. Services at salon A were limited to haircuts, facial hair trimmings, and perms. Most stylists cut hair while clients are facing away from them, which might have also limited transmission.

The results of this study can be used to inform public health policy during the COVID-19 pandemic. A policy mandating the use of face coverings was likely a contributing factor in preventing transmission of SARS-CoV-2 during the close-contact interactions between stylists and clients in salon A. Consistent and correct use of face coverings, when appropriate, is an important tool for minimizing spread of SARS-CoV-2 from presymptomatic, asymptomatic, and symptomatic persons. CDC recommends workplace policies regarding use of face coverings for employees and clients in addition to daily monitoring of signs and symptoms of employees, procedures for screening employees who arrive with or develop symptoms at work, and posted messages to inform and educate employees and clients (https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/businesses-employers.html).

Acknowledgments

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How Face Masks Can Help Prevent the Spread of COVID-19

As communities and businesses reopen amidst the pandemic, masks in addition to other social distancing measures are crucial for preventing new outbreaks.

Diana Kwon
Jul 8, 2020

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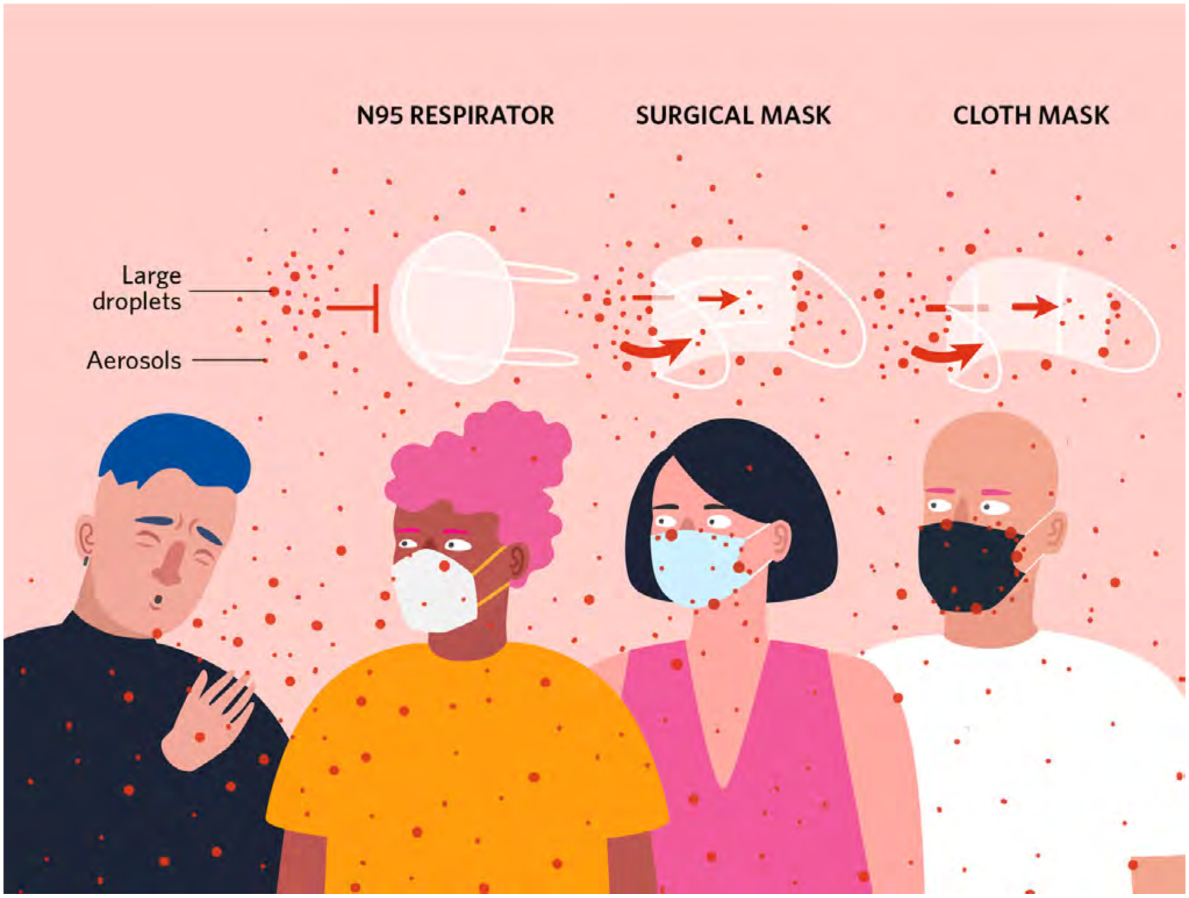
Face masks have been a matter of intense debate during the COVID-19 pandemic. Early on, several government officials and health authorities were discouraging healthy people from wearing masks—noting that there was little evidence for the practice's ability to prevent spread among the general public and citing concerns that protective face coverings, which were desperately needed by healthcare workers, were in short supply. Gradually, however, governments began to either require or recommend that their citizens wear face masks in public. In June, the World Health Organization (WHO) recommended widespread mask-use as a way to prevent coronavirus transmission. One model estimates that if at least 95 percent of people wear masks in public between June and October, approximately 33,000 deaths could be avoided in the US.

There are three broad categories of face coverings: tight-fitting masks known as N95 respirators that are designed to filter out both aerosols (often defined as particles that are smaller than 5 micrometers in diameter) and larger airborne droplets, loose-fitting surgical masks that are fluid resistant and capable of filtering out the bigger particles, and cloth masks, which vary widely based on how they're made.

Different Types of Masks



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N95 respirator: Tight-fitting single-use masks typically made with synthetic materials such as polyester and polypropylene. These masks are able to filter out at least 95 percent of both large airborne droplets and aerosols.

Surgical/medical masks: Loose-fitting single-use masks made with three or more layers of synthetic materials. These can filter out large airborne particles, but some aerosols can leak through, and particle-containing air is able to flow around the edges.

Fabric masks: These often-homemade masks vary widely in their construction and effectiveness. Aerosols are likely to leak through, and particle-containing air is able to flow around the edges. With appropriate washing or a couple of days to decontaminate, fabric masks are reusable.

See full infographic: WE

A growing body of research supports the use of all three types of masks, though the quality of evidence varies. One of the most comprehensive examinations to date, published in *The Lancet* in early June, systemically assessed 172 observational studies—mostly conducted in healthcare settings—looking at the effect of physical distancing, face masks, and eye protection on the transmission of SARS-CoV-2 and two related coronaviruses. The results revealed that N95 respirators provided 96 percent protection from infection and surgical masks (or comparable reusable masks made with 12 to 16 layers of cotton or gauze) were 67 percent protective.

While research on cloth masks is much more limited, one group of researchers demonstrated that, in the lab, multilayer masks made of hybrid materials (cotton and silk, for example) could filter up to 90 percent of particles between 300 nanometers and 6 micrometers in size. However, it's important to note this is only the case when there are no gaps around the edges of the mask, which are often present when people wear cloth or surgical masks. Indeed, the researchers' findings suggest that gaps around any mask can reduce filtration by 60 percent or more. Still, scientists using computational models have reported that, in general, widespread use of facemasks, when combined with lockdowns, may help prevent future waves of infection.

"We're recommending that N95s still be primarily saved for the healthcare situation," says Kirsten Koehler, a professor of environmental health and engineering at Johns Hopkins University. "For individuals in the public, wearing a fabric mask is probably still the way to go."

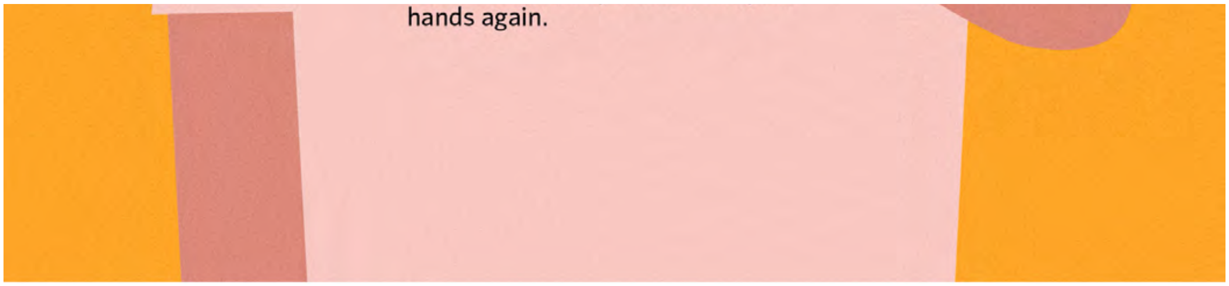
There are several factors, including the number of layers and type of material they are made from, that contribute to how effective a mask will be, explains Raina MacIntrye, a professor of global biosecurity at the University of New South Wales in Australia. According to the WHO, fabric masks should ideally have at least three layers: an inner layer made with absorbent material (e.g., cotton), an outer layer with water-resistant material (e.g., polyester), and a middle layer (made with absorbent or water-resistant material) to act as a filter. In addition, MacIntrye adds, "the design should fit around the edges of the face because air will flow down the path of least resistance." In other words, if there are gaps on the sides of your mask, your breath will slip through those cracks instead of being filtered through the mask itself.

None of these masks are going to be perfect, especially against the aerosols.

—Kirsten Koehler, Johns Hopkins University

Although evidence is building to support the use of masks to stem the coronavirus' spread, many questions remain, such as whether the coronavirus spreads through aerosols or just through larger respiratory droplets. There is also little research on the efficacy of face masks, particularly cloth ones, in stopping the spread of COVID-19 in community settings, Julii Brainard, a senior research associate at Norwich Medical School in the UK, tells *The Scientist* in an email.

Amidst the uncertainty, what is clear is that mask wearing is not the only action people should take to slow the spread of COVID-19, Koehler says. "None of these masks are going to be perfect, especially against the aerosols. You want to continue to encourage people to work from home, avoid being crowds—things like that are going to work, regardless of how good your mask is."



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Face coverings for the public: Laying straw men to rest

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Abstract

Background

This article responds to one by Graham Martin and colleagues, who offered a critique of my previous publications on face coverings for the lay public in the Covid-19 pandemic. Their paper reflects criticisms that have been made of face coverings policies more generally.

Method

Narrative rebuttal.

Results

I address charges that my coauthors and I had misapplied the precautionary principle; drawn conclusions that were not supported by empirical research; and failed to take account of potential harms

But before that, I remind my critics that the evidence on face coverings goes beyond the contested trials and observational studies they place centre stage. I set out some key findings from basic science, epidemiology, mathematical modelling, case studies, and natural experiments, and use this rich and diverse body of evidence as the backdrop for my rebuttal of their narrowly framed objections. I challenge my critics' apparent assumption that a particular kind of systematic review should be valorised over narrative and real-world evidence, since stories are crucial to both our scientific understanding and our moral imagination.

Conclusion

I conclude by thanking my academic adversaries for the intellectual sparring match, but exhort them to remember our professional accountability to a society in crisis. It is time to lay straw men to rest and embrace the full range of evidence in the context of the perilous threat the world is now facing.

KEYWORDS

evidence-based medicine, public health, systematic reviews

1 | INTRODUCTION

Since the Covid-19 pandemic emerged, I have coauthored several articles in both the academic and lay literature supporting the wearing of face coverings and masks by the general public.[1-3] In response to negative criticism on social media, I put out a challenge: either write a point by point critique of my papers or back off. Martin et al responded with a preprint paper[4] and a rapid BMJ response.[5] The points made in their publications reflect those of other critics of face coverings as a policy response to Covid-19.

Later in this article, I will address the substantive scientific points made by Martin et al, which I will put in italics. I have tried to represent their points faithfully, without exaggeration, and apologize in advance if I have not captured their intended nuances. But first, let me highlight a subtle rhetorical move by Martin et al: *they completely ignore various types of evidence*—including basic science, mathematical modelling and real-world case examples of asymptomatic transmission and super-spreader events. Before addressing what they did talk about in their paper,[4] I set out some important scientific evidence that they did *not* talk about. I draw heavily on the primary sources cited in the narrative review by Howard et al.[6] I deliberately avoid the term "mask" when referring to a cloth face covering (either home-made or purchased) used by a member of the public.

2 | A WIDER EVIDENCE BASE

The basic science of Covid-19 is important. The Sars-CoV-2 virus which causes this disease replicates in the upper respiratory tract (in contrast to the causative agent of Sars-CoV-1, which is a less contagious lower respiratory tract virus).[7,8] This means it is likely to be transmitted mainly by droplets (which is why there is so much emphasis on hand-washing, since droplets contaminate surfaces).[9] Droplets emitted from the human respiratory tract (which are relatively large, and are emitted not just by coughing and sneezing but also by speaking[10]) quickly turn into aerosols (smaller microdroplets),[11] so unless they are controlled at source, they become much harder to block.

A crucially important point, which is often overlooked by doctors, systematic reviewers and the lay press (and which was not addressed at all by Martin et al), is that most research on masks and face coverings—almost all of which has been undertaken in the context of health care workers—considers the extent to which they *protect the wearer*. The current question we need to address is a different one: whether covering the face *protects other people from droplets emitted by the wearer*—a measure known as source control. Source control works in a different way to wearer-protection—by blocking large droplets as they are emitted in coughing, sneezing, and talking and before they become aerosolised.[10,12-14] Large droplets (and indeed a proportion of aerosols) are blocked—not perfectly, but significantly—by cotton home-made coverings.[10,15-18]

Face coverings that protect the wearer work by blocking tiny aerosolised particles. For this reason, medical-grade masks need to meet stringent filtration standards, about which much has been written (see for example[19]). In contrast, source control face coverings can potentially be very effective even if they only block the larger droplet particles. Studies of the efficacy of masks in protecting the wearer are therefore irrelevant to the question of source control.

Evidence of asymptomatic carriage of Sars-CoV-2 is strong and consistent. Oran and Topol have analysed (to date) 12 such examples from around the world,[20] including cohorts identified for nationwide testing (Iceland), local population testing (Vo, Italy), passengers or crew of three ships (Diamond Princess, USS Theodore Roosevelt, and Charles de Gaulle aircraft carrier), nursing home staff and residents (United States), residents of two homeless shelters (Boston and Los Angeles), ex-pats (Japanese evacuated from Wuhan and Greek citizens evacuated from other countries), and pregnant women (New York City obstetric patients). In these diverse cohorts, between 31% and 88% of positive cases were asymptomatic or presymptomatic when tested. A recent editorial in the New England Journal of Medicine argued that the exceptionally high rates of asymptomatic transmission of Sars-CoV-2 call for a different approach to infection control—specifically, masks or face coverings for the public.[21]

In contrast to the high transmission rates from such individuals in this case series, there are some impressive case examples of infected individuals *not* passing on the virus when wearing a mask. For example one man flew from China to Toronto wearing a mask for the entire flight, became symptomatic the next day and tested positive for covid-19; none of the other passengers or crew became infected.[22]

Another piece of evidence that covering the face could make a big difference is super-spreader events, a list of which has been compiled by Kay.[20] Perhaps the most dramatic is the choir practice in Seattle, in which, despite maintaining a degree of social distancing during the rehearsal, 45 of 60 people became infected and two (so far) have died.[23] In all these super-spreader events, extensive transmission was traced back to close contact—but not necessarily physical touching. As the authors put it: "*When do COVID-19 [super-spreader events] happen? … Wherever and whenever people are up in each other's faces, laughing, shouting, cheering, sobbing, singing, greeting, and praying*."

In relation to a community-wide intervention such as face coverings, we do not need to prevent every transmission of every droplet or every viral particle. As with hand-washing and social distancing, the objective of the policy is more modest: to achieve a *substantial reduction* in the transmission rate of the virus. Every infectious disease has a transmission rate (R0). A disease with an R0 of 1.0 means that each infected person, on average, infects one other person. A disease whose R0 is less than 1.0 will die out. The strain of flu that caused the 1918 pandemic had an R0 of 1.8. The R0 of Sars-CoV-2 was estimated at 2.4 by Imperial College researchers,[24] and other research suggests it could even higher.[25] A population measure that reduces the transmission rate ("effective R0" or R_{eff}) to below 1.0 will be highly effective, *even if some cases of transmission still occur*.

Mathematical modelling suggests that a face covering that is 60% effective at blocking viral transmission and is worn by 60% of the population will reduce R0 to below 1.0.[26] This leaves plenty of room for error as people make their own imperfect coverings from old clothing and as some people either cannot or will not wear a face covering. Not all respiratory viruses are filtered equally; masks appear to be more efficient at blocking Sars-Cov-2 than rhinoviruses or adenoviruses, for example.[27] Materials scientists have shown that whilst different fabrics are more or less efficient at blocking particle transmission, cotton weaves with high thread count or a double layer of two different fabrics (eg, cotton-flannel) typically provides high filtration efficiency.[28]

Case 5:20-3048-E-SK Document 23-27-1 Page 445 Date Filed: 11/06/2020

There are now many natural experiments of the wearing of masks or face coverings in Covid-19, as countries introduce either mandatory or voluntary policies. Of note is the example of the Czech Republic and Austria, both of which introduced social distancing on the same day; the former also introduced compulsory face coverings. New covid-19 infections fell more quickly in the Czech Republic, and only began to fall in Austria after masks were made mandatory 2 weeks later,[3] though an alternative interpretation of this natural experiment is that Austrian data was confounded by changes in testing policy.[29] Also noteworthy is the observation that every single country where masks or cloth face coverings have been introduced as national policy (often but not always alongside other measures), rates of transmission fell in the subsequent days.

All these various streams of evidence contribute, in different ways and at different levels, to strengthen the argument for recommending face coverings, especially in crowded public places where social distancing is impossible, during the pandemic. With this wider evidentiary context sketched, let me now take on the specific claims made by Martin et al in their paper and rapid response.[4,5]

3 | PRECAUTIONARY PRINCIPLE, "WEAK" EVIDENCE AND POTENTIAL HARMS

> *The precautionary principle we invoked to justify wearing of masks*[1] *is, Martin et al imply, irrelevant, because it is normally used to advise caution in the uptake of innovations with known benefits but uncertain or unmeasurable downsides, such as exposure of the public to radiation.*

The term "precautionary principle" does not have a fixed meaning, though I accept that it is more usually invoked as described by Martin et al. It may surely prove equally appropriate (a) when harm is not currently happening but a proposed intervention may cause harm and (b) when serious harm is currently happening and a proposed intervention may reduce that harm. There seems to me to be a strong symmetry between these examples. One does not cancel the other out. Both the omission in the former case and the act in the latter case are measures aimed at preventing harm.

> *"[T]he very weak evidence for face masks should be reiterated". Trials, say Martin et al, have shown no evidence of reduced transmission with masks compared to no masks, and observational studies are contaminated with multiple confounders (e.g. parallel introduction of other measures such as hand washing).*

The evidence base for face coverings (described above) is not weak. However, it was a weak rhetorical move for Martin et al to ignore the strongest evidence when penning their critique. Our BMJ analysis article briefly reviewed the literature from experimental trials and systematic reviews.[1] Two preprint systematic reviews[30,31] and a narrative review[6] were all published the same week. In all those syntheses, there is a conspicuous *absence of experimental evidence* in relation to the wearing of masks *in public places, by the lay public*, as ***source control*** to *prevent community transmission* of any respiratory illness.

The sum total of randomized trials and observational studies covered in these reviews, *all of which are irrelevant to the question of source control*, comprise: (a) studies of mask-wearing within the home to reduce contagion to other family members[32-41]; (b) studies of occupational exposure (eg, workers in poultry factories)[42,43]; (c) studies of specific mass events (notably, pilgrimages to the Hajj)[44-50]; (d) studies in schools and university halls of residence[51-54]; (e) studies of air travel[55]; (f) studies of health care workers[40,56-58]; and just two studies of general community prevention: an attempt to prevent the common cold in Finland,[59] and a paper on behavioural measures (among other things) in the prevention of SARS, in which those who "always" wore a mask when outside the home had a relative risk of developing the disease of 0.3 compared to those who "never" wore one.[60]

Almost all these primary studies were designed to test the hypothesis that wearing a mask in the specific situation described in (a) to (g) above *protects the wearer*; one or two considered the specific question of whether mask-wearing by a sick family member protects others in the household.[35,36,41] The question my colleagues and I have addressed in our articles[1-3] was a completely different one: whether a face covering worn by a member of the general public *protects others in the community*. Martin et al's depiction of the evidence from trials and observational cohort studies as "very weak" is incorrect. Such randomized controlled trial evidence, in relation to source control, is *entirely absent* and unrelated evidence should not be presented as a possible answer (Note: this does not mean there is no evidence at all—merely, that there is no evidence valued by the RCT community).

Absence of trial evidence is partly due to the fact that experimental studies of mass public health measures are usually impractical. We do not randomize schools to close, towns to go into lockdown, people to sneeze into their elbows or whole communities to wash their hands regularly. That is simply not how mass public health interventions get tested.[61] The argument that we should not recommend face coverings *because there are no published experiments* is out of step with other public health policy on infection control in general and covid-19 in particular. As with other public health measures, we should make a decision based on an assessment of the full body of evidence described above.

> *Wearing face masks may cause harm, say Martin et al, specifically (citing the Jefferson systematic review*[3]*) "discomfort, dehydration, facial dermatitis, distress, headaches, exhaustion."*

It is widely reported that prolonged use of personal protective equipment by health care personnel in pandemic contexts is associated with all the problems listed (though exhaustion in particular may have other explanations in such circumstances). Some research studies have confirmed that prolonged wearing of medical-grade masks by

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health care workers can result in physical and psychological harms.[62-65] However, neither Martin et al nor the Jefferson systematic review which they cite offer any evidence whatsoever that the use of home-made face coverings by the lay public for source control has been shown to cause such harms. Indeed, there is no common sense reason why a covering made out of one's own old t-shirt would cause illness when the t-shirt itself was well-tolerated (and if it wasn't, why make a mask out of it?). The possible harmful effects of face coverings (eg, anecdotal accounts of irritation behind the ears from ill-fitting elastic) should also be weighed against their potential benefits, and the potential advantages of novel equipment such as face screens (clear plastic visors) urgently researched.[66]

4 | CAN THE GENERAL PUBLIC BE TRUSTED?

> *The general public, propose Martin et al, are unlikely to use masks "properly". Even healthcare workers struggle to achieve necessary standards of donning and doffing technique, and "inappropriately discarded masks present an infection risk".*

Infection control standards designed for health care workers are not directly relevant to the general public. The infected particles on a health care worker's mask are likely to come from patients, and in this situation the health care worker is (hopefully) uninfected and therefore vulnerable. In contrast, if a member of the public is wearing a cloth face covering, they are the most likely source of any infectious particles on it. The more infectious particles that are caught in that covering, the fewer will have been aerosolised to infect others. A face covering that has been removed does not need to be disinfected, and formal doffing is not needed (though hand-washing would be sensible in case the covering has become contaminated with droplets from others). Sars-CoV-2 has a lipid membrane which is destroyed by soap or detergent (this, of course, is why hand-washing works). A cloth face covering can be laundered along with other clothing in a normal hot wash.[67] An alternative option in low-income countries is to wash the covering with soap and water and leave it to dry in the sun. Imposing unnecessarily high standards of disinfection on the public is likely to reduce uptake of the measure and be counterproductive.

> *Being able to make, don, doff and disinfect your own cloth mask, suggest Martin et al, is a middle-class privilege. The efficacy of masks in the general population will be reduced by "the potential for great variation in materials, fit, adherence, touching and adjustment, doffing, disposal, frequency of laundering and so on".*

There is no need to standardize the design of masks or fetishise how they are worn, any more than we do so for the shoes that protect our feet or the t-shirts we pull over our faces. Cotton and similar materials do not block droplets entirely—but most double-layer fabrics seem to filter up to 90% of them, especially if two different fabrics with different physical and electrostatic properties are used.[15-18] There is some evidence that the Sars-CoV-2 virus relies more heavily than influenza, adenoviruses, or rhinoviruses on droplets, and will thus be more easily filtered out by a cloth cover at source than other respiratory viruses.[68,69] As noted above, if 60% of people wear a mask that is 60% effective, this is likely to be sufficient to substantially reduce the transmission of Sars-CoV-2. To say that because some people may find it difficult to obtain or launder a mask or face cover, we should not recommend them for anyone is illogical—especially since adverse socioeconomic circumstances is a risk factor for developing Covid-19 and also for poorer prognosis.[70] The negative, individualist emphasis of Martin et al's critique ignores the positive impact of collectively making face coverings as a component of wider community resilience strategies in Covid-19.[71,72] The South African Government, for example, has recently issued a tender for community sewing cooperatives to supply cloth face masks.[73]

> *Risk compensation (in which people made to wear masks reduced other infection control behaviours such as hand-washing), suggest Martin et al, could occur.*

My critics cite a review from 20 years ago which describes mixed findings on risk compensation behaviours.[74] They do not cite a more recent review which suggests that such behaviours appear rare.[75] Both these reviews, however, focused mainly on injury prevention, not on infection control measures. More relevant perhaps are studies showing that teenagers vaccinated against human papilloma virus do not appear to take more sexual risks,[76,77] though there is some evidence that pre-exposure prophylaxis for HIV may increase sexual risk-taking in men who have sex with men.[78] The argument that risk compensation behaviour would occur specifically in relation to face coverings in the context of Covid-19 is entirely speculative. It is also unlikely. If adverse behaviour change happens to a significant degree, we would surely have seen some examples from around the world by now, as numerous countries have now made the wearing of masks or face coverings mandatory. Two recent studies from Hong Kong, based on self-reports in online or telephone surveys (hence, relatively weak evidence), found that those who reported wearing masks in public places were also more likely to report more hand-washing and social distancing.[79,80]

5 | UNINTENDED CONSEQUENCES?

> *[U]niversal mask-wearing might aggravate the climate of fear already documented for Covid-19.*

Fear is perhaps a reasonable response to a deadly pandemic that has so far affected at least three million people and cost hundreds of thousands of lives. There is no evidence that policies which encourage or mandate covering the face increase fear. The counterargument—that such a measure would help *reduce* fear—is equally plausible (though there is no definitive evidence either way). In studies of community mask use in tuberculosis control, mask-wearing by affected individuals reduced disease transmission but increased stigma,[81,82] whereas promotion of mask-wearing by all members of the community was associated with destigmatisation.[82] The relevance of these findings to the current pandemic are unclear.

> *Promoting mask-wearing by the lay public could lead to a shortage of medical-grade masks.*

This is a real concern, but it is not a reason to distort or deny the evidence of benefit. There is no reason why the public should wear medical-grade masks, since cotton face coverings are more comfortable, recyclable, and sufficiently effective for source control, especially given the evidence on how this particular virus behaves (it sits in the upper respiratory tract and is emitted mostly in droplets).[68,69] A public information campaign would be needed to get this message across to lay people as well as to clinicians and scientists (most of whom, like Martin et al, have unjustifiable extrapolated findings from research on infection control in health care settings and sought to apply the same standards to the public). In any case, simple surgical masks could surely be produced easily and in large numbers by repurposing manufacturing capacity if the political will and logistical capability was there.[83]

> *[B]usinesses or states might see widespread or mandatory mask-wearing as a warrant for a premature return to 'business as usual,' justifying unsafe workplaces or crowded commuting conditions in terms of the protection offered by masks.*[4]

This statement is entirely speculative. No evidence is given for it and it implies that the preferred state is for society to remain in lockdown indefinitely.[84] The risks to the economy of prolonged lockdown are dire.[85,86] Recession and job losses will have a disproportionate effect on the poor and socially excluded. There are ethical as well as scientific arguments for considering all measures that may help to reduce the lockdown period and get businesses up and running as a matter of urgency.

> *Masks, suggest Martin et al, are an example of a complex intervention in a complex system. Their effects are impossible to predict, therefore we should not introduce them.*

The papers cited to support this assertion (one of which was coauthored by me[87]) actually support the opposite conclusion. Just because a complex system is unpredictable does not mean we should do nothing.[88] As Martin et al acknowledge, careful data collection and frequent, timely analysis that feeds into adjustment of policy will allow an adaptive and data-driven response. Their depiction of current United Kingdom policy as too "blunt" to respond in this way is conflating politics with science. It is not a legitimate reason to sit idle when hundreds are dying daily.

6 | "SYSTEMATIC" VS NARRATIVE REVIEWS

In the first paragraph of their paper, Martin et al contrast "two [preprint] systematic reviews" with "another preprint review, with more opaque methods but encompassing an eclectic range of disciplinary perspectives." The implication is that the conclusions of "systematic" reviews which favour controlled experiments are necessarily more reliable than those of "opaque" and "eclectic" narrative reviews which bring in so-called anecdotal evidence and findings from basic and social sciences. Elsewhere, colleagues and I have challenged this conceptual bias.[89] In that paper, we distinguish between narrowly defined biomedical questions that can be answered using conventional systematic review, with meta-analysis where appropriate, and more complex, multifaceted problems that require *clarification and insight*, for which a more interpretive and discursive synthesis of is needed.

Looking back at the first part of this article, where I summarized the evidence that Martin et al chose to ignore, I am struck by the *stories* they did not examine (the Covid-stricken choir, the air passenger whose mask may have saved a planeload of people from contagion, the cruise ships that became floating quarantine prisons). But these stories are crucial to both our scientific understanding and our moral imagination. Their contrasting plots—tragedy, melodrama, lucky escape—pull together complex chains of influence and remind us that causality in a pandemic is rarely linear. Anecdotes may be a low form of evidence in some taxonomies, but each one calls for an explanation.

As my coauthors and I concluded in out article on narrative review:

> *Training in systematic reviews has produced a generation of scholars who are skilled in the technical tasks of searching, sorting, checking against inclusion criteria, tabulating extracted data and generating 'grand means' and confidence intervals. These skills are important, but … critics may incorrectly assume that they override and make redundant the generation of understanding. … While there are occasions when systematic review is the ideal approach to answering specific forms of questions, the absence of thoughtful, interpretive critical reflection can render such products hollow, misleading and potentially harmful.*[89]

7 | CONCLUSION

In conclusion, I congratulate Martin et al for rising to my challenge to produce a critique of my publications on masks and face coverings for the public. But whilst academic sparring has an important place in keeping us on our toes, we also need to remember our moral accountability to a society in crisis. The relentless, day on day stories of avoidable deaths from this dreadful disease sicken me. I will do whatever I can, as an academic, a doctor and a citizen, to reduce that death toll and help get society back running again.

As Gandhi et al concluded in their NEJM editorial: "This unprecedented pandemic calls for unprecedented measures to achieve its ultimate defeat."[21] It is time to put the straw men to rest and embrace the full range of evidence in the context of the perilous threat the world is now facing.

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E HIBIT

Visualizing the effectiveness of face masks in obstructing respiratory jets

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ABSTRACT

The use of face masks in public settings has been widely recommended by public health officials during the current COVID-19 pandemic. The masks help mitigate the risk of cross-infection via respiratory droplets; however, there are no specific guidelines on mask materials and designs that are most effective in minimizing droplet dispersal. While there have been prior studies on the performance of medical-grade masks, there are insufficient data on cloth-based coverings, which are being used by a vast majority of the general public. We use qualitative visualizations of emulated coughs and sneezes to examine how material- and design-choices impact the extent to which droplet-laden respiratory jets are blocked. Loosely folded face masks and bandana-style coverings provide minimal stopping-capability for the smallest aerosolized respiratory droplets. Well-fitted homemade masks with multiple layers of quilting fabric, and off-the-shelf cone style masks, proved to be the most effective in reducing droplet dispersal. These masks were able to curtail the speed and range of the respiratory jets significantly, albeit with some leakage through the mask material and from small gaps along the edges. Importantly, uncovered emulated coughs were able to travel notably farther than the currently recommended 6-ft distancing guideline. We outline the procedure for setting up simple visualization experiments using easily available materials, which may help healthcare professionals, medical researchers, and manufacturers in assessing the effectiveness of face masks and other personal protective equipment qualitatively.

Infectious respiratory illnesses can exact a heavy socio-economic toll on the most vulnerable members of our society, as has become evident from the current COVID-19 pandemic.[1,2] The disease has overwhelmed healthcare infrastructure worldwide,[3] and its high contagion rate and relatively long incubation period[4,5] have made it difficult to trace and isolate infected individuals. Current estimates indicate that about 35% of infected individuals do not display overt symptoms[6] and may contribute to the significant spread of the disease without their knowledge. In an effort to contain the unabated community spread of the disease, public health officials have recommended the implementation of various preventative measures, including social-distancing and the use of face masks in public settings.[7]

The rationale behind the recommendation for using masks or other face coverings is to reduce the risk of cross-infection via the transmission of respiratory droplets from infected to healthy individuals.[8,9] The pathogen responsible for COVID-19 is found primarily in respiratory droplets that are expelled by infected individuals during coughing, sneezing, or even talking and breathing.[10–15] Apart from COVID-19, respiratory droplets are also the primary means of transmission for various other viral and bacterial illnesses, such as the common cold, influenza, tuberculosis, SARS (Severe Acute Respiratory Syndrome), and MERS (Middle East Respiratory Syndrome), to name a few.[16–19] These pathogens are enveloped within respiratory droplets, which may land on healthy individuals and result in direct transmission, or on inanimate objects, which can lead to infection when a healthy individual comes in contact with them.[10,18,20,21] In another mode of transmission, the droplets or their evaporated contents may remain suspended in the air for long periods of time if they are sufficiently small. This can lead to airborne transmission[19,22] when they are breathed in by another person, long after the infected individual may have left the area.

Several studies have investigated respiratory droplets produced by both healthy and infected individuals when performing various activities. The transport characteristics of these droplets can vary significantly depending on their diameter.[23–28] The reported droplet diameters vary widely among studies available in the literature and usually lie within the range 1 μm–500 μm,[29] with a mean diameter of ~10 μm.[30] The larger droplets (diameter >100 μm) are observed to follow ballistic trajectories under the effects of gravity and aerodynamic drag.[20,31] Intermediate-sized droplets[20,31,32] may get carried over considerable distances within a multiphase turbulent cloud.[33–35] The smallest droplets and particles (diameter < 5 μm–10 μm) may remain suspended in the air indefinitely, until they are carried away by a light breeze or ventilation airflow.[20,32]

After being expelled into the ambient environment, the respiratory droplets experience varying degrees of evaporation depending on their size, ambient humidity, and temperature. The smallest droplets may undergo complete evaporation, leaving behind a dried-out spherical mass consisting of the particulate contents (e.g., pathogens), which are referred to as "droplet nuclei."[36] These desiccated nuclei, in combination with the smallest droplets, are potent transmission sources on account of two factors: (1) they can remain suspended in the air for hours after the infected individual has left the area, potentially infecting unsuspecting individuals who come into contact with them and (2) they can penetrate deep into the airways of individuals who breathe them in, which increases the likelihood of infection even for low pathogen loads. At present, the role of droplet nuclei in the transmission of COVID-19 is not known with certainty and the matter is the subject of ongoing studies.[37–39] In addition to generating microscopic droplets, the action of sneezing can expel sheet-like layers of respiratory fluids,[40] which may break apart into smaller droplets through a series of instabilities. The majority of the fluid contained within the sheet falls to the ground quickly within a short distance.

Regardless of their size, all droplets and nuclei expelled by infected individuals are potential carriers of pathogens. Various studies have investigated the effectiveness of medical-grade face masks and other personal protective equipment (PPE) in reducing the possibility of cross-infection via these droplets.[13,33,41–47] Notably, such respiratory barriers do not prove to be completely effective against extremely fine aerosolized particles, droplets, and nuclei. The main issue tends to be air leakage, which can result in aerosolized pathogens being dispersed and suspended in the ambient environment for long periods of time after a coughing/sneezing event has occurred. A few studies have considered the filtration efficiency of homemade masks made with different types of fabric;[48–51] however, there is no broad consensus regarding their effectiveness in minimizing disease transmission.[52,53] Nonetheless, the evidence suggests that masks and other face coverings are effective in stopping larger droplets, which, although fewer in number compared to the smaller droplets and nuclei, constitute a large fraction of the total volume of the ejected respiratory fluid.

While detailed quantitative measurements are necessary for the comprehensive characterization of PPE, qualitative visualizations can be invaluable for rapid iteration in early design stages, as well as for demonstrating the proper use of such equipment. Thus, one of the aims of this Letter is to describe a simple setup for visualization experiments, which can be assembled using easily available materials. Such setups may be helpful to healthcare professionals, medical researchers, and industrial manufacturers, for assessing the effectiveness of face masks and other protective equipment qualitatively. Testing designs quickly and early on can prove to be crucial, especially in the current pandemic scenario where one of the central objectives is to reduce the severity of the anticipated resurgence of infections in the upcoming months.

The visualization setup used in the current study is shown in Fig. 1 and consists of a hollow manikin head which was padded on the inside to approximate the internal shape and volume of the nasal- and buccal-cavities in an adult. In case a more realistic representation is required, such a setup could include 3D-printed or silicone models of the internal airways. The manikin was mounted at a height of ~5 ft and 8 in. to emulate respiratory jets expelled by an average human male. The circular opening representing the mouth is 0.75 in. in diameter. The pressure impulse that emulates a cough or a sneeze may be delivered via a manual pump, as shown in Fig. 1, or via other sources such as an air compressor or a pressurized air canister. The air capacity of the pump is 500 ml, which is comparable to the lower end of the total volume expelled during a cough.[54] We note that the setup here emulates a simplified representation of an actual cough, which is an extremely complex and dynamic problem.[55] We use a recreational fog/smoke machine to generate tracer particles for visualizing the expelled respiratory jets, using a liquid mixture of distilled water (4 parts) and glycerin (1 part). Both the pressure- and smoke-sources were connected to the manikin using clear vinyl tubing and NPT fittings wherever necessary.

The resulting "fog" or "smoke" is visible in the right panel of Fig. 1 and is composed of microscopic droplets of the vaporized liquid mixture. These are comparable in size to the smallest droplets expelled in a cough jet (~1 μm–10 μm). We estimate that the fog droplets are less than 10 μm in diameter, based on Stokes' law and our observation that they could remain suspended for up to 3 min in completely still air with no perceptible settling. The laser source used to generate the visualization sheet is an off-the-shelf 5 mW green laser pointer with 532 nm wavelength. A plane vertical sheet is created by passing the laser beam

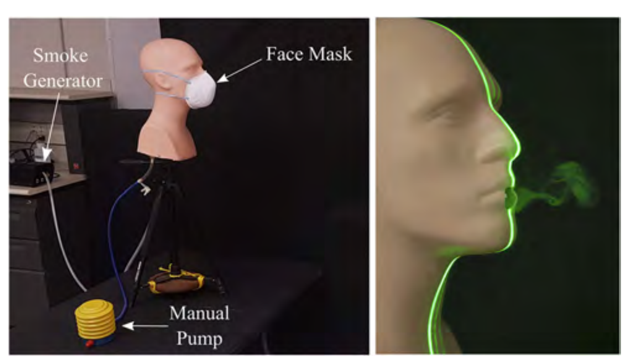

FIG. 1. Left—experimental setup for qualitative visualization of emulated coughs and sneezes. Right—a laser sheet illuminates a puff emerging from the mouth.

through a thin cylindrical rod (diameter 5 mm) made of borosilicate glass.

We first present visualization results from an emulation of an uncovered heavy cough. The spatial and temporal evolution of the resulting jet is shown in Fig. 2. The aerosolized microscopic droplets visible in the laser sheet act as tracer particles, revealing a two-dimensional cross section of the conical turbulent jet. These tracers depict the fate of the smallest ejected droplets and any resulting nuclei that may form. We observed high variability in droplet dispersal patterns from one experimental run to another, which was caused by otherwise imperceptible changes in the ambient airflow. This highlights the importance of designing ventilation systems that specifically aim to minimize the possibility of cross-infection in a confined setting.[23,56–58]

Despite high variability, we consistently observed jets that traveled farther than the 6-ft minimum distance proposed by the U.S. Centers for Disease Control and Prevention (CDC's).[7] In the images shown in Fig. 2, the ejected tracers were observed to travel up to 12 ft within ~50 s. Moreover, the tracer droplets remained suspended midair for up to 3 min in the quiescent environment. These observations, in combination with other recent studies,[35,59] suggest that current social-distancing guidelines may need to be updated to account for the aerosol-based transmission of pathogens. We note that although the unobstructed turbulent jets were observed to travel up to 12 ft, a large majority of the ejected droplets will fall to the ground by this point. Importantly, both the number and concentration of the droplets will decrease with increasing distance,[59] which is the fundamental rationale behind social-distancing.

We now discuss dispersal patterns observed when the mouth opening was blocked using three different types of face masks. For these results, we focus on masks that are readily accessible to

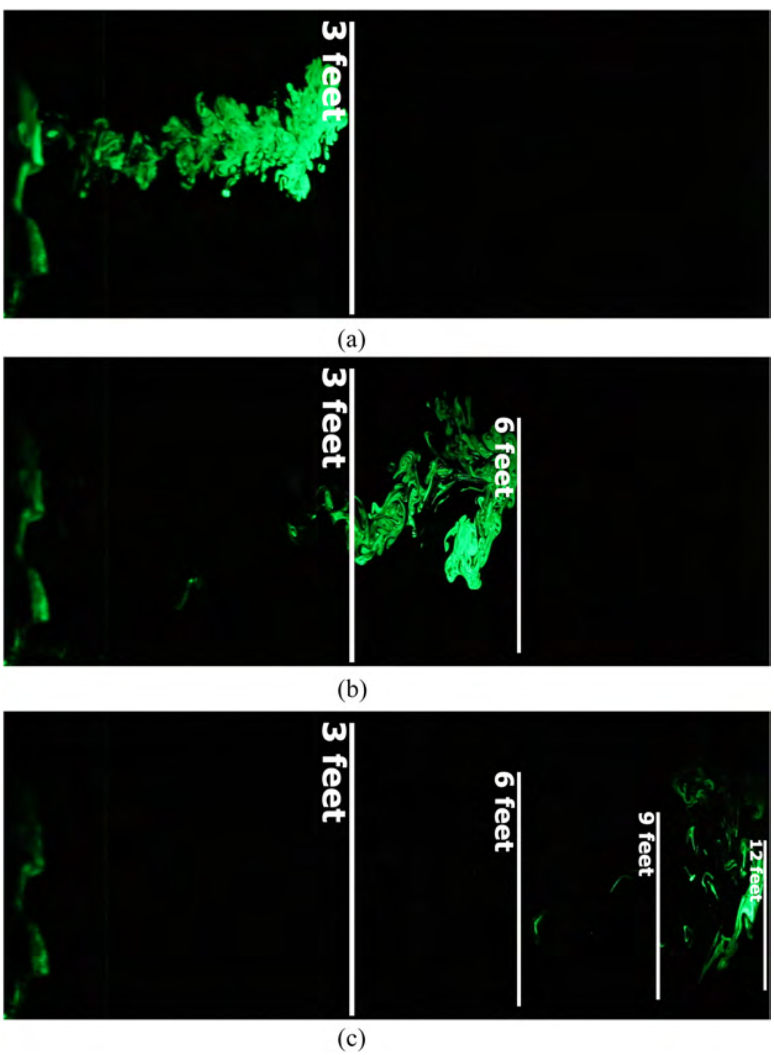

FIG. 2. An emulated heavy cough jet travels up to 12 ft in ~50 s, which is twice the CDC's recommended distancing guideline of 6 ft.[7] Images taken at (a) 2.3 s, (b) 11 s, and (c) 53 s after the initiation of the emulated cough.

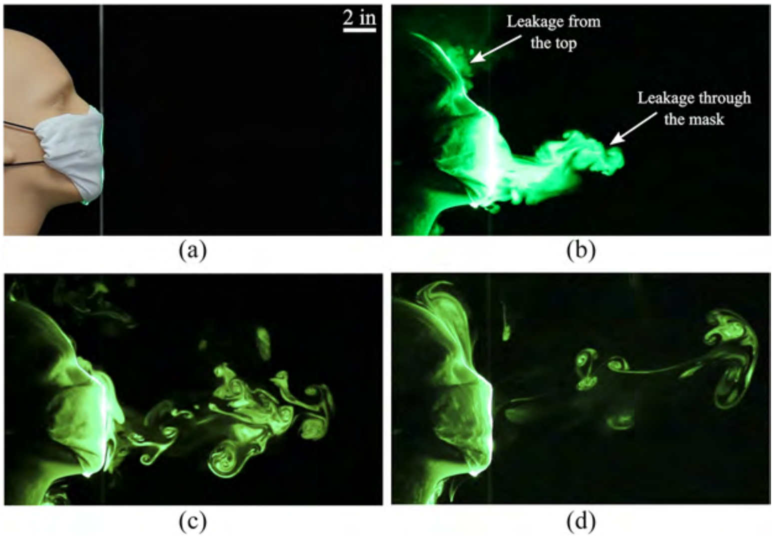

FIG. 3. (a) A face mask constructed using a folded handkerchief. Images taken at (b) 0.5 s, (c) 2.27 s, and (d) 5.55 s after the initiation of the emulated cough.

the general public, which do not draw away from the supply of medical-grade masks and respirators for healthcare workers. Figure 3 shows the impact of using a folded cotton handkerchief mask on the expelled respiratory jet. The folded mask was constructed by following the instructions recommended by the U.S. Surgeon General.[60] It is evident that while the forward motion of the jet is impeded significantly, there is notable leakage of tracer droplets through the mask material. We also observe a small amount of tracers escaping from the top edge of the mask, where gaps exist between the nose and the cloth material. These droplets remained suspended in the air until they were dispersed by ambient disturbances. In addition to the folded handkerchief mask discussed here, we tested a single-layer bandana-style covering (not shown) which proved to be substantially less effective in stopping the jet and the tracer droplets.

We now examine a homemade mask that was stitched using two-layers of cotton quilting fabric consisting of 70 threads/in. The mask's impact on droplet dispersal is shown in Fig. 4. We observe that the mask is able to arrest the forward motion of the tracer droplets almost completely. There is minimal forward leakage through the material, and most of the tracer-escape happens from the gap between the nose and the mask along the top edge. The forward distance covered by the leaked jet is less than 3 in. in this case. The final mask design that we tested was a non-sterile cone-style mask that is available in most pharmacies. The corresponding droplet-dispersal visualizations are shown in Fig. 5, which indicate that the flow is impeded significantly compared to Figs. 2 and 3. However, there is noticeable leakage from gaps along the top edge. The forward distance covered by the leaked jet is ~6 in. from the mouth opening, which is farther than the distance for the stitched mask in Fig. 4.

A summary of the various scenarios examined in this study is provided in Table I, along with details about the mask material and the average distances traveled by the respiratory jets. We observe that a single-layer bandana-style covering can reduce the range of the expelled jet to some extent, compared to an uncovered cough.

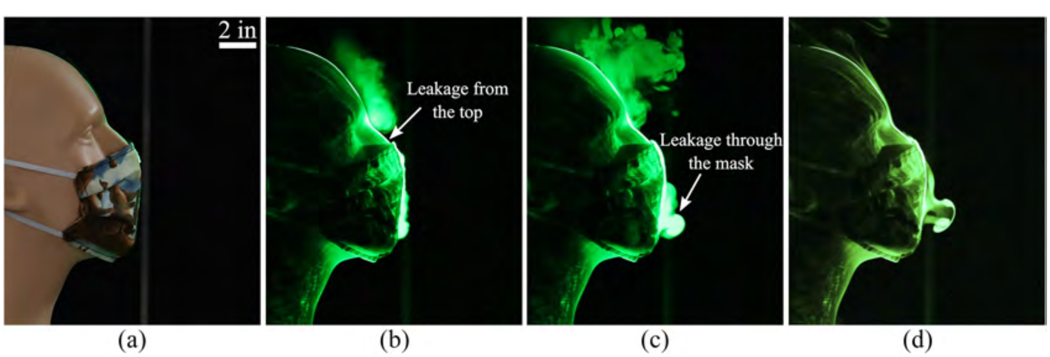

FIG. 4. (a) A homemade face mask stitched using two-layers of cotton quilting fabric. Images taken at (b) 0.2 s, (c) 0.47 s, and (d) 1.68 s after the initiation of the emulated cough.

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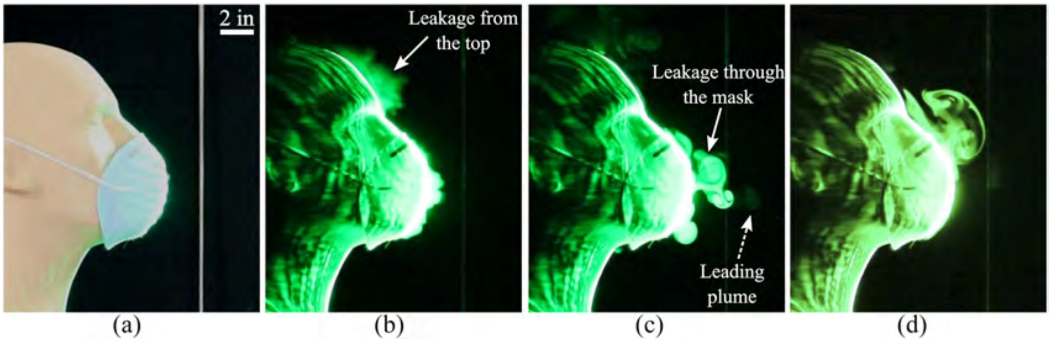

FIG. 5. (a) An off-the-shelf cone style mask. (b) 0.2 s after initiation of the emulated cough. (c) 0.97 s after initiation of the emulated cough. The leading plume, which has dissipated considerably, is faintly visible. (d) 3.7 s after initiation of the emulated cough.

TABLE I. A summary of the different types of masks tested, the materials they are made of, and their effectiveness in impeding droplet-dispersal. The last column indicates the distance traveled by the jet beyond which its forward progression stops. The average distances have been computed over multiple runs, and the symbol "~" is used to indicate the presence of high variability in the first two scenarios listed.

Mask type	Material	Threads/in.	Average jet distance
Uncovered	...	...	~8 ft
Bandana	Elastic T-shirt material	85	~3 ft 7 in.
Folded handkerchief	Cotton	55	1 ft 3 in.
Stitched mask	Quilting cotton	70	2.5 in.
Commercial mask[a]	Unknown	Randomly assorted fibres	8 in.

[a]CVS Cone Face Mask.

Importantly, both the material and construction techniques have a notable impact on the masks' stopping-capability. The stitched mask made of quilting cotton was observed to be the most effective, followed by the commercial mask, the folded handkerchief, and, finally, the bandana. Importantly, our observations suggest that a higher thread count by itself is not sufficient to guarantee better stopping-capability; the bandana covering, which has the highest thread count among all the cloth masks tested, turned out to be the least effective.

We note that it is likely that healthcare professionals trained properly in the use of high-quality fitted masks will not experience leakage to the extent that we have observed in this study. However, leakage remains a likely issue for members of the general public who often rely on loose-fitting homemade masks. Additionally, the masks may get saturated after prolonged use, which might also influence their filtration capability. We reiterate that although the non-medical masks tested in this study experienced varying degrees of flow leakage, they are likely to be effective in stopping larger respiratory droplets.

In addition to providing an initial indication of the effectiveness of protective equipment, the visuals used in this study can help convey to the general public the rationale behind social-distancing guidelines and recommendations for using face masks. Promoting widespread awareness of effective preventative measures is crucial, given the high likelihood of a resurgence of COVID-19 infections in the fall and winter.

DATA AVAILABILITY

The data that support the findings of this study are available within this article.

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E HIBIT AAA

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CORRESPONDENCE

Visualizing Speech-Generated Oral Fluid Droplets with Laser Light Scattering

TO THE EDITOR: Aerosols and droplets generated during speech have been implicated in the person-to-person transmission of viruses,[1,2] and there is current interest in understanding the mechanisms responsible for the spread of Covid-19 by these means. The act of speaking generates oral fluid droplets that vary widely in size,[1] and these droplets can harbor infectious virus particles. Whereas large droplets fall quickly to the ground, small droplets can dehydrate and linger as "droplet nuclei" in the air, where they behave like an aerosol and thereby expand the spatial extent of emitted infectious particles.[2] We report the results of a laser light-scattering experiment in which speech-generated droplets and their trajectories were visualized.

The output from a 532-nm green laser operating at 2.5-W optical power was transformed into a light sheet that was approximately 1 mm thick and 150 mm tall. We directed this light sheet through slits on the sides of a cardboard box measuring 53×46×62 cm. The interior of the box was

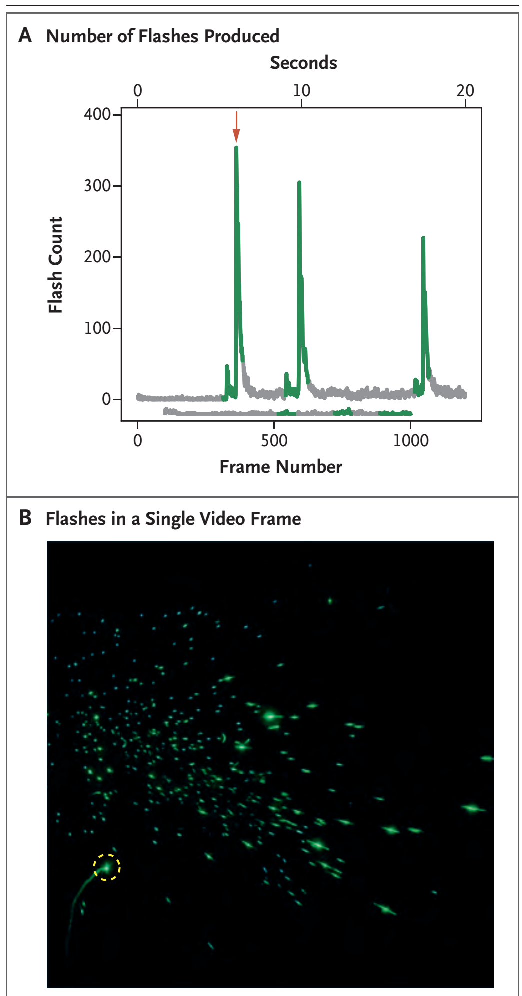

Figure 1. Emission of Droplets While a Person Said "Stay Healthy."

Droplets generated during speech produced flashes as they passed through the light sheet in this experiment. Panel A shows the flash count during each frame of a video produced at a rate of 60 frames per second, with and without a damp cloth covering the speaker's mouth. Green indicates spoken words. The number of flashes was highest (arrow) when the "th" sound in the word "healthy" was pronounced. The trace offset below the graph shows that when the speaker's mouth was covered with a damp cloth, there was no qualitative increase in the flash count during speech over the background level observed before the first trial of speech. The flash count during the silent periods between the spoken phrases remained above the background level, a finding that suggests that some of the speech droplets lingered inside the box for some seconds. Panel B shows frame 361 from the video, which corresponds to the red arrow in Panel A and to the highest number of speech droplets visualized in an individual frame of the video recording. The spots vary in brightness because of the differences in the size of the particles. Some of the spots are streaked, which suggests that the rate of 60 frames per second was insufficient to freeze the motion of the droplets. The feature highlighted by a dashed yellow circle corresponds to the tip of a very thin wire positioned just behind the light sheet; this wire provided a reference for setting the camera focus and gain before recording. (See the video, available at NEJM.org.)

painted black. The enclosure was positioned under a high-efficiency particulate air (HEPA) filter to eliminate dust.

When a person spoke through the open end of the box, droplets generated during speech traversed approximately 50 to 75 mm before they encountered the light sheet. An iPhone 11 Pro video camera aimed at the light sheet through a hole (7 cm in diameter) on the opposite side of the box recorded sound and video of the light-scattering events at a rate of 60 frames per second. The size of the droplets was estimated from ultrahigh-resolution recordings. Video clips of the events while the person was speaking, with and without a face mask, are available with the full text of this letter at NEJM.org.

A video showing the experiment is available at NEJM.org

We found that when the person said "stay healthy," numerous droplets ranging from 20 to 500 μm were generated. These droplets produced flashes as they passed through the light sheet (Fig. 1). The brightness of the flashes reflected the size of the particles and the fraction of time they were present in a single 16.7-msec frame of the video. The number of flashes in a single frame of the video was highest when the "th" sound in the word "healthy" was pronounced (Fig. 1A). Repetition of the same phrase three times, with short pauses in between the phrases, produced a similar pattern of generated particles, with peak numbers of flashes as high as 347 with the loudest speech and as low as 227 when the loudness was slightly decreased over the three trials (see the top trace in Fig. 1A). When the same phrase was uttered three times through a slightly damp washcloth over the speaker's mouth, the flash count remained close to the background level (mean, 0.1 flashes); this showed a decrease in the number of forward-moving droplets (see the bottom trace in Fig. 1A).

We found that the number of flashes increased with the loudness of speech; this finding was consistent with previous observations by other investigators.[3] In one study, droplets emitted during speech were smaller than those emitted during coughing or sneezing. Some studies have shown that the number of droplets produced by speaking is similar to the number produced by coughing.[4]

We did not assess the relative roles of droplets generated during speech, droplet nuclei,[2] and aerosols in the transmission of viruses. Our aim was to provide visual evidence of speech-generated droplets and to qualitatively describe the effect of a damp cloth cover over the mouth to curb the emission of droplets.

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ARTICLE

Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks

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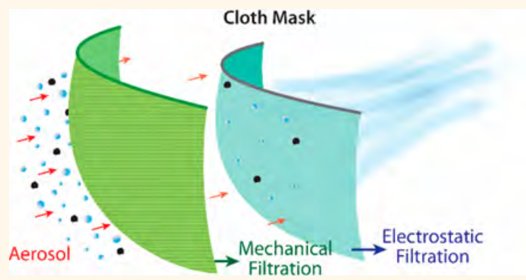
ABSTRACT: **The emergence of a pandemic affecting the respiratory system can result in a significant demand for face masks. This includes the use of cloth masks by large sections of the public, as can be seen during the current global spread of COVID-19. However, there is limited knowledge available on the performance of various commonly available fabrics used in cloth masks. Importantly, there is a need to evaluate filtration efficiencies as a function of aerosol particulate sizes in the 10 nm to 10 μm range, which is particularly relevant for respiratory virus transmission. We have carried out these studies for several common fabrics including cotton, silk, chiffon, flannel, various synthetics, and their combinations. Although the filtration efficiencies for various fabrics when a single layer was used ranged from 5 to 80% and 5 to 95% for particle sizes of <300 nm and >300 nm, respectively, the efficiencies improved when multiple layers were used and when using a specific combination of different fabrics. Filtration efficiencies of the hybrids (such as cotton−silk, cotton−chiffon, cotton−flannel) was >80% (for particles <300 nm) and >90% (for particles >300 nm). We speculate that the enhanced performance of the hybrids is likely due to the combined effect of mechanical and electrostatic-based filtration. Cotton, the most widely used material for cloth masks performs better at higher weave densities (*i.e.*, thread count) and can make a significant difference in filtration efficiencies. Our studies also imply that gaps (as caused by an improper fit of the mask) can result in over a 60% decrease in the filtration efficiency, implying the need for future cloth mask design studies to take into account issues of "fit" and leakage, while allowing the exhaled air to vent efficiently. Overall, we find that combinations of various commonly available fabrics used in cloth masks can potentially provide significant protection against the transmission of aerosol particles.**



KEYWORDS: *cloth masks, personal protection, aerosols, SARS-CoV-2, face masks, respiratory protection, COVID-19*

The use of cloth masks, many of them homemade,[1,2] has become widely prevalent in response to the 2019−2020 SARS-CoV-2 outbreak, where the virus can be transmitted *via* respiratory droplets.[3−6] The use of such masks is also an anticipated response of the public in the face of future pandemics related to the respiratory tract. However, there is limited data available today on the performance of common cloth materials used in such cloth masks,[7−12] particularly their filtration efficiencies as a function of different aerosol sizes ranging from ∼10 nm to ∼10 μm scale sizes. This is also of current significance as the relative effectiveness of different droplet sizes in transmitting the SARS-CoV-2 virus is not clear, and understanding the filtration response across a large bracketed size distribution is therefore important.[13−16] In this paper, we report the results of experiments where we measure the filtration efficiencies of a number of common fabrics, as well as selective combinations for use as hybrid cloth masks, as a function of aerosol sizes ranging from ∼10 nm to 6 μm. These include cotton, the most widely used fabric in cloth masks, as well as fabric fibers that can be electrostatically charged, such as natural silk.

Respiratory droplets can be of various sizes[17,18] and are commonly classified as aerosols (made of droplets that are <5 μm) and droplets that are greater than 5 μm.[3] Although the fate of these droplets largely depends on environmental factors such as humidity, temperature, *etc.*, in general, the larger droplets settle due to gravity and do not travel distances more than 1−2 m.[19] However, aerosols remain suspended in the air for longer durations due to their small size and play a key role in spreading infection.[14−16] The use of physical barriers such as

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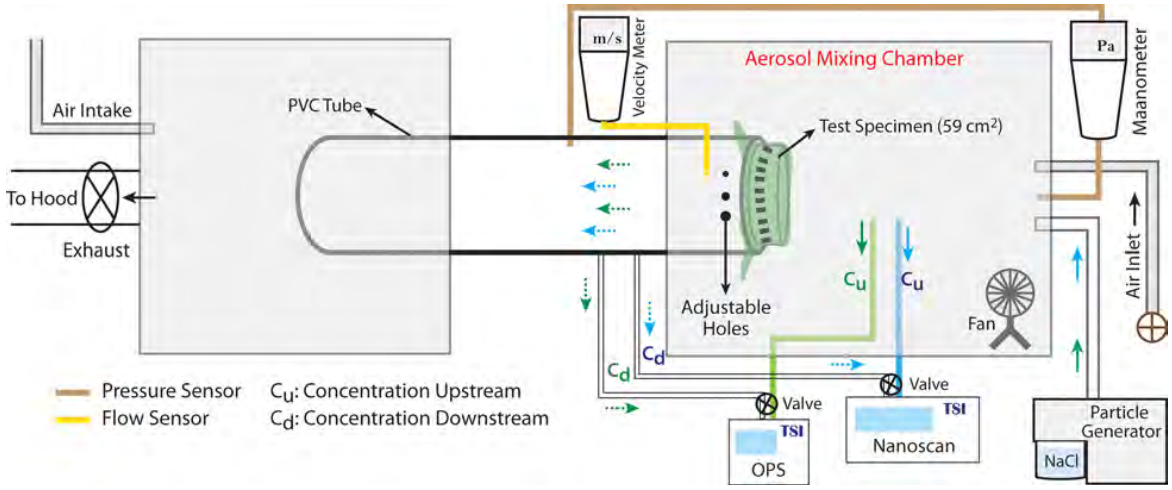

Figure 1. Schematic of the experimental setup. A polydisperse NaCl aerosol is introduced into the mixing chamber, where it is mixed and passed through the material being tested ("test specimen"). The test specimen is held in place using a clamp for a better seal. The aerosol is sampled before (upstream, C_u) and after (downstream, C_d) it passes through the specimen. The pressure difference is measured using a manometer, and the aerosol flow velocity is measured using a velocity meter. We use two circular holes with a diameter of 0.635 cm to simulate the effect of gaps on the filtration efficiency. The sampled aerosols are analyzed using particle analyzers (OPS and Nanoscan), and the resultant particle concentrations are used to determine filter efficiencies.

respiratory masks can be highly effective in mitigating this spread *via* respiratory droplets.[20−22] Filtration of aerosols follows five basic mechanisms: gravity sedimentation, inertial impaction, interception, diffusion, and electrostatic attraction.[23,24] For aerosols larger than ~1 μm to 10 μm, the first two mechanisms play a role, where ballistic energy or gravity forces are the primary influence on the large exhaled droplets. As the aerosol size decreases, diffusion by Brownian motion and mechanical interception of particles by the filter fibers is a predominant mechanism in the 100 nm to 1 μm range. For nanometer-sized particles, which can easily slip between the openings in the network of filter fibers, electrostatic attraction predominates the removal of low mass particles which are attracted to and bind to the fibers. Electrostatic filters are generally most efficient at low velocities such as the velocity encountered by breathing through a face mask.[25]

There have been a few studies reported on the use of cloth face masks mainly during or after the Influenza Pandemic in 2009;[8−12,26] However, there is still a lack of information that includes (i) the performance of various fabrics as a function of particle size from the nanoscale to the micron sized (particularly important because this covers the ~10 nm to ~5 μm size scale for aerosols) and (ii) the effect of hybrid multilayer approaches for masks that can combine the benefits of different filtering mechanisms across different aerosol size ranges.[9,26] These have been the objectives of the experimental work described in this paper. In addition, we also point out the importance of fit (that leads to gaps) while using the face mask.[27,28]

The experimental apparatus (see Figure 1) consists of an aerosol generation and mixing chamber and a downstream collection chamber. The air flows from the generation chamber to the collection chamber through the cloth sample that is mounted on a tube connecting the two chambers. The aerosol particles are generated using a commercial sodium chloride (NaCl) aerosol generator (TSI Particle Generator, model #8026), producing particles in the range of a few tens of nanometers to approximately 10 μm. The NaCl aerosol based testing is widely used for testing face respirators in compliance with the NIOSH 42 CFR Part 84 test protocol.[29,30] Two different particle analyzers are used to determine particle size dimensions and concentrations: a TSI Nanoscan SMPS nanoparticle sizer (Nanoscan, model #3910) and a TSI optical particle sizer (OPS, model #3330) for measurements in the range of 10 to 300 nm and 300 nm to 6 μm, respectively.

Particles are generated upstream of the cloth sample, whose filtration properties are to be tested, and the air is drawn through the cloth using a blower fan which can be controlled in order to vary the airflow rate. Effective area of the cloth sample during the tests was ~59 cm^2. Measurements of particle size and distribution were made by sampling air at a distance of 7.5 cm upstream and 15 cm downstream of the cloth sample. The differential pressures and air velocities were measured using a TSI digital manometer (model #AXD620) and a TSI Hot Wire anemometer (model #AVM410). The differential pressure (ΔP) across the sample material is an indicator of the comfort and breathability of the material when used as a face mask.[31] Tests were carried out at two different airflows: 1.2 and 3.2 CFM, representative of respiration rates at rest (~35 L/min) and during moderate exertion (~90 L/min), respectively.[32]

The effect of gaps between the contour of the face and the mask as caused by an improper fit will affect the efficiency of any face mask.[21,27,28,33] This is of particular relevance to cloth and surgical masks that are used by the public and which are generally not "fitted", unlike N95 masks or elastomeric respirators. A preliminary study of this effect was explored by drilling holes (symmetrically) in the connecting tube onto which the fabric (or a N95 or surgical mask) is mounted. The holes, in proximity to the sample (Figure 1), resulted in openings of area ~0.5−2% of the active sample area. This, therefore, represented "leakage" of the air around the mask.

Although the detailed transmission specifics of SARS-CoV-2 virus are not well understood yet, droplets that are below 5 μm are considered the primary source of transmission in a respiratory infection,[13,15,34] and droplets that are smaller than

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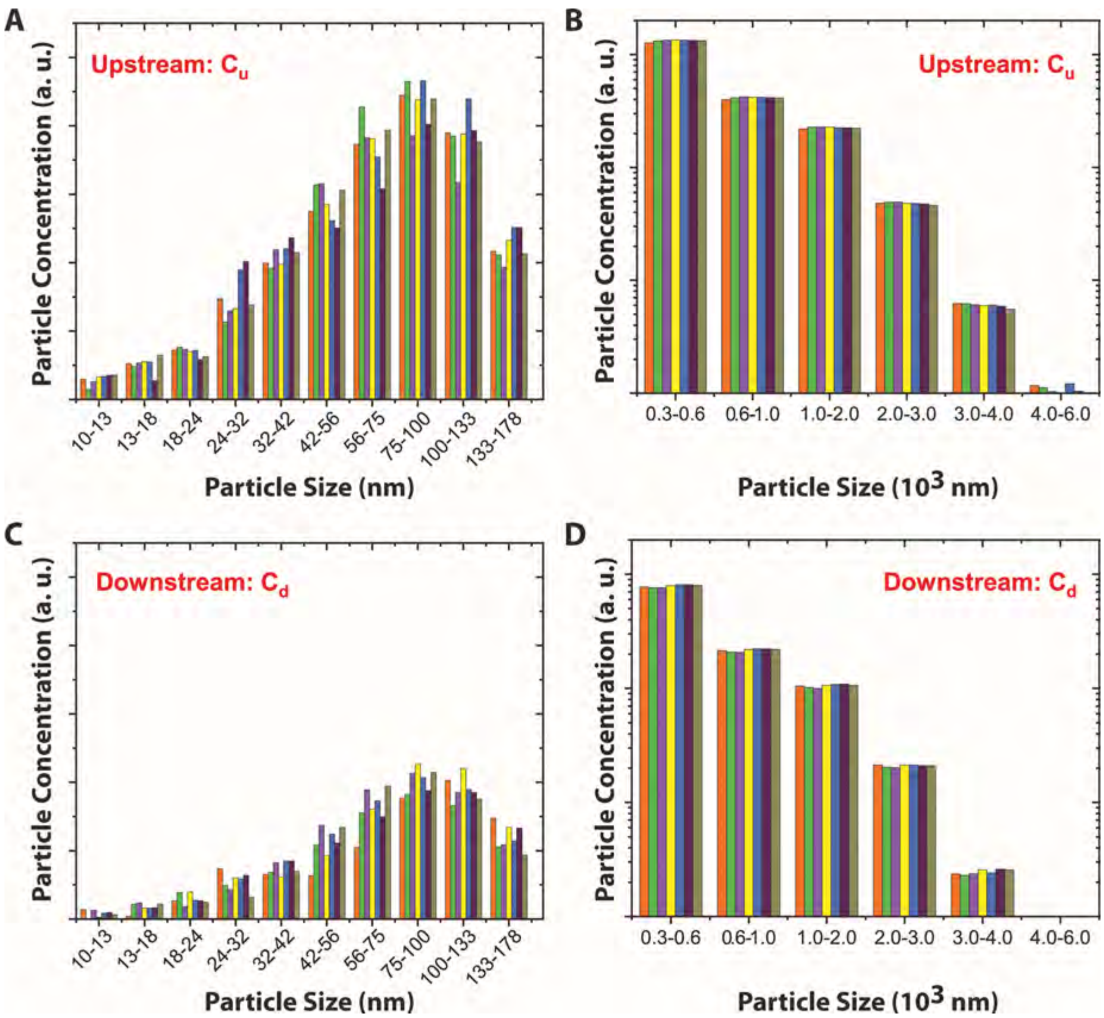

Figure 2. Particle concentration as a function of particle size at a flow rate of 1.2 CFM. Plots showing the particle concentration (in arbitrary units) upstream and downstream through a single layer of natural silk for particle sizes <300 nm (a,c) and between 300 nm and 6 μm (b,d). Each bin shows the particle concentration for at least six trials. The particle concentrations in panels (b) and (d) are given in log scale for better representation of the data. The y-axis scales are the same for panels "a" and "c"; and for panels "b" and "d".

1 μm tend to stay in the environment as aerosols for longer durations of up to 8 h.[19] Aerosol droplets containing the SARS-CoV-2 virus have been shown to remain suspended in air for ~3 h.[13,35] We have therefore targeted our experimental measurements in the important particle size range between ~10 nm and 6 μm.

We tested the performance of over 15 natural and synthetic fabrics that included materials such as cotton with different thread counts, silk, flannel, and chiffon. The complete list is provided in the Materials and Methods section. For comparison, we also tested a N95 respirator and surgical masks. Additionally, as appropriate, we tested the efficiency of multiple layers of a single fabric or a combination of multiple fabrics for hybrid cloth masks in order to explore combinations of physical filtering as well as electrostatic filtering.

RESULTS AND DISCUSSION

We determine the filtration efficiency of a particular cloth as a function of particle size (Figure 2) by measuring the concentration of the particles upstream, C_u (Figure 2a,b) and the concentration of the particle downstream, C_d (Figure 2c,d). Concentrations were measured in the size ranges of 10−178 nm (using the nanoscan tool) and 300 nm to 6 μm (using the optical particle sizer tool). The representative example in Figure 2 shows the case for a single layer of silk fabric, where the measurements of C_u and C_d were carried out at a flow rate of 1.2 CFM. Following the procedure detailed in the Materials and Methods section, we then estimated the filtration efficiency of a cloth from C_u and C_d as a function of aerosol particle size.

The results plotted in Figure 3a are the filtration efficiencies for cotton (the most common material used in cloth masks) with different thread counts (rated in threads per inch—TPI—and representative of the coarseness or fineness of the fabric). We compare a moderate (80 TPI) thread count quilter's cotton (often used in do-it-yourself masks) with a high (600 TPI) cotton fabric sample. Additionally, we also measured the transmission through a traditional cotton quilt where two 120 TPI quilter's cotton sheets sandwich a ~0.5 cm batting (90% cotton−5% polyester−5% other fibers). Comparing the two

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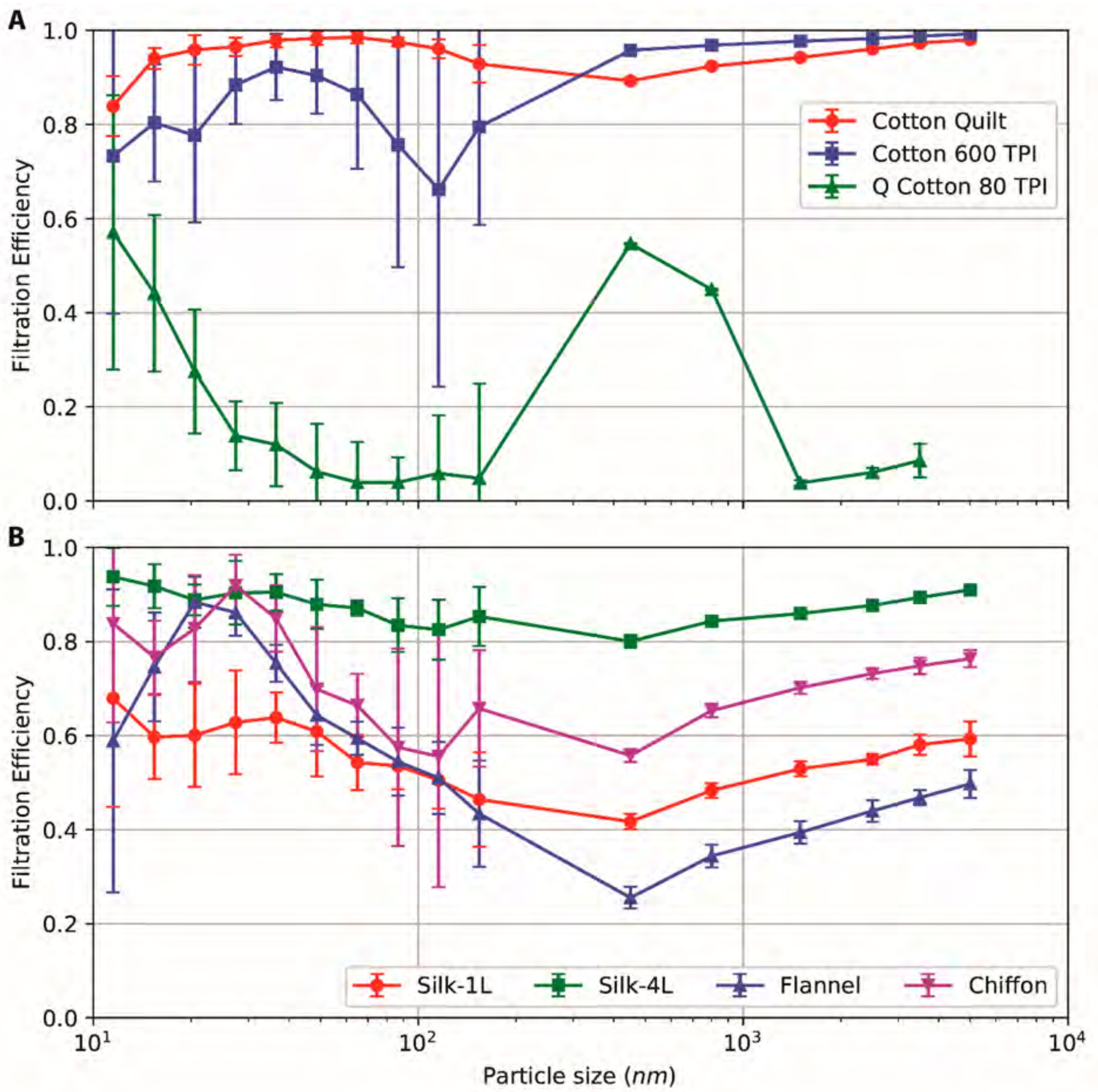

Figure 3. Filtration efficiency of individual fabrics at a flow rate of 1.2 CFM (without gap). (a) Plot showing the filtration efficiencies of a cotton quilt consisting of two 120 threads per inch (TPI) cotton sheets enclosing a ∼0.5 cm thick cotton batting, 80 TPI quilters cotton (Q Cotton 80 TPI), and a 600 TPI cotton (cotton 600 TPI). (b) Plot showing the filtration efficiencies of one layer of natural silk (Silk-1L), four layers of natural silk (Silk-4L), one layer of flannel, and one layer of chiffon. The error bars on the <300 nm measurements are higher, particularly for samples with high filtration efficiencies because of the small number of particles generated in this size range, the relatively poorer counting efficiency of the detector at <300 nm particle size, and the very small counts downstream of the sample. The sizes of the error bars for some of the data points (>300 nm) are smaller than the symbol size and hence not clearly visible.

cotton sheets with different thread counts, the 600 TPI cotton is clearly superior with >65% efficiency at <300 nm and >90% efficiency at >300 nm, which implies a tighter woven cotton fabric may be preferable. In comparison, the single-layer 80 TPI cotton does not perform as well, with efficiencies varying from ∼5 to ∼55% depending on the particle size across the entire range. The quilt, a commonly available household material, with a fibrous cotton batting also provided excellent filtration across the range of particle sizes (>80% for <300 nm and >90% for >300 nm).

Electrostatic interactions are commonly observed in various natural and synthetic fabrics.[36,37] For instance, polyester woven fabrics can retain more static charge compared to natural fibers or cotton due to their lower water adsorption properties.[36] The electrostatic filtering of aerosols have been well studied.[38] As a result, we investigated three fabrics expected to possess moderate electrostatic discharge value: natural silk, chiffon (polyester−Spandex), and flannel (cotton−polyester).[36] The results for these are shown in Figure 3b. In the case of silk, we made measurements through one, two, and four layers of the fabric as silk scarves are often wrapped in multiple layers around the face (the results for two layers of silk are presented in Figure S1 (Supporting Information) and omitted from this figure). In all of these cases, the performance in filtering nanosized particles <300 nm is superior to performance in the 300 nm to 6 μm range and particularly effective below ∼30 nm, consistent with the expectations from the electrostatic effects of these materials. Increasing the number of layers (as

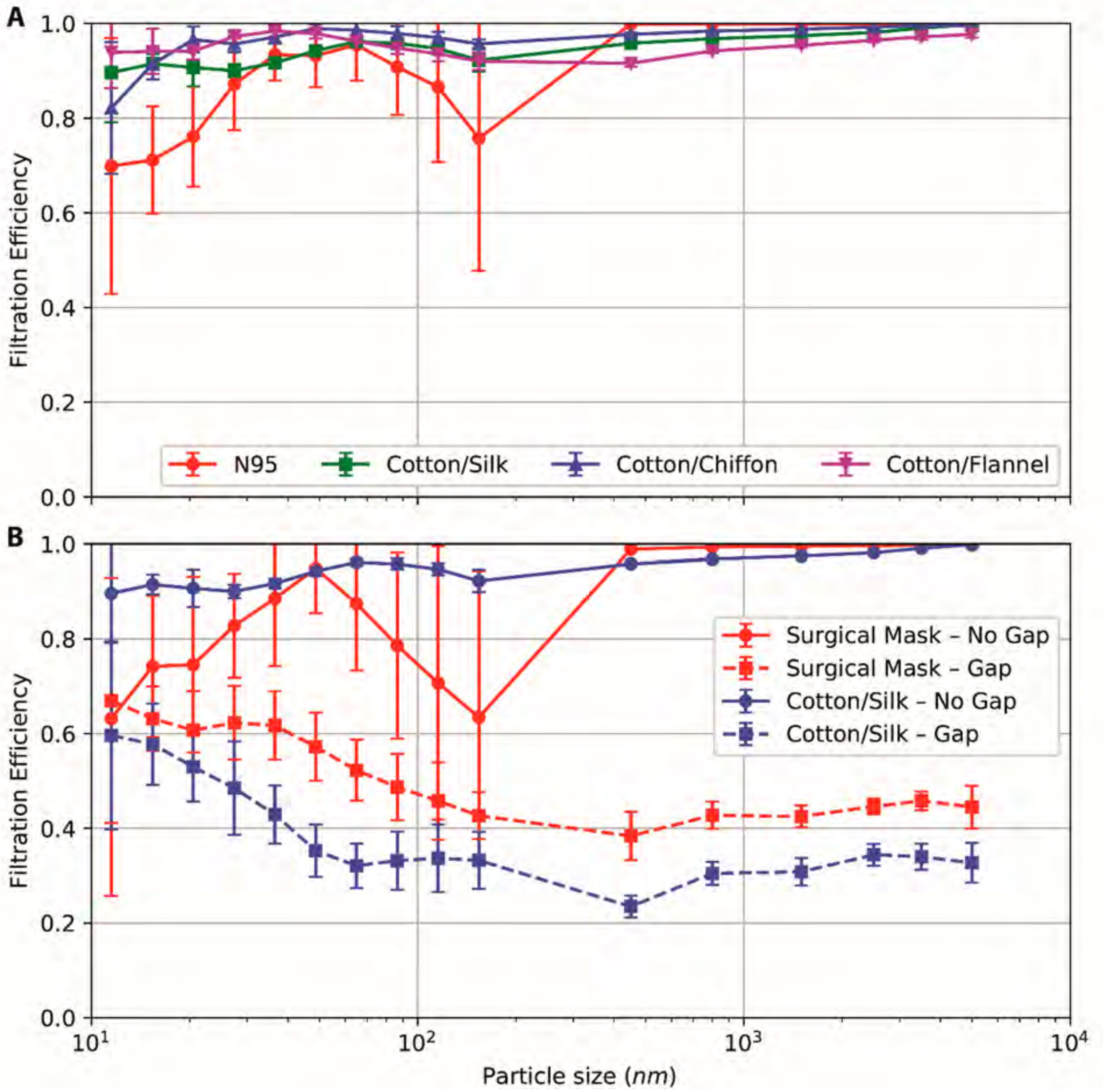

Figure 4. Filtration efficiency of hybrid fabrics at a flow rate of 1.2 CFM. (a) Plot showing the filtration efficiencies without gap for an N95 respirator and a combination of different fabrics: 1 layer of 600 threads per inch (TPI) cotton and 2 layers of silk (cotton/silk), 1 layer of 600 TPI cotton and 2 layers of chiffon (cotton/chiffon), and 1 layer of 600 TPI cotton and 1 layer of flannel (cotton/flannel). (b) Plot showing the filtration efficiencies of a surgical mask and cotton/silk with (dashed) and without a gap (solid). The gap used is ~1% of the active mask surface area. The error bars on the <300 nm measurements are higher, particularly for samples with high filtration efficiencies because of the small number of particles generated in this size range, the relatively poorer counting efficiency of the detector at <300 nm particle size, and the very small counts downstream of the sample. The sizes of the error bars for some of the data points (>300 nm) are smaller than the symbol size and hence not clearly visible.

shown for silk in Figure 3b), as expected, improves the performance. We performed additional experiments to validate this using the 600 TPI cotton and chiffon (Figure S1). We note that the performance of a four-layer silk composite offers >80% filtration efficiency across the entire range, from 10 nm to 6 μm.

In Figure 4a, we combine the nanometer-sized aerosol effectiveness (for silk, chiffon, and flannel) and wearability (of silk and chiffon because of their sheer nature) with the overall high performance of the 600 TPI cotton to examine the filtration performance of hybrid approaches. We made measurements for three variations: combining one layer 600 TPI cotton with two layers of silk, two layers of chiffon, and one layer of flannel. The results are also compared with the performance of a standard N95 mask. All three hybrid combinations performed well, exceeding 80% efficiency in the <300 nm range, and >90% in the >300 nm range. These cloth hybrids are slightly inferior to the N95 mask above 300 nm, but superior for particles smaller than 300 nm. The N95 respirators are designed and engineered to capture more than 95% of the particles that are above 300 nm,[39,40] and therefore, their underperformance in filtering particles below 300 nm is not surprising.

It is important to note that in the realistic situation of masks worn on the face without elastomeric gasket fittings (such as the commonly available cloth and surgical masks), the

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Table 1. Filtration Efficiencies of Various Test Specimens at a Flow Rate of 1.2 CFM and the Corresponding Differential Pressure (Δ*P*) across the Specimen[a]

	flow rate: 1.2 CFM		
	filter efficiency (%)		pressure differential
sample/fabric	<300 nm average ± error	>300 nm average ± error	Δ*P* (Pa)
N95 (no gap)	85 ± 15	99.9 ± 0.1	2.2
N95 (with gap)	34 ± 15	12 ± 3	2.2
surgical mask (no gap)	76 ± 22	99.6 ± 0.1	2.5
surgical mask (with gap)	50 ± 7	44 ± 3	2.5
cotton quilt	96 ± 2	96.1 ± 0.3	2.7
quilter's cotton (80 TPI), 1 layer	9 ± 13	14 ± 1	2.2
quilter's cotton (80 TPI), 2 layers	38 ± 11	49 ± 3	2.5
flannel	57 ± 8	44 ± 2	2.2
cotton (600 TPI), 1 layer	79 ± 23	98.4 ± 0.2	2.5
cotton (600 TPI), 2 layers	82 ± 19	99.5 ± 0.1	2.5
chiffon, 1 layer	67 ± 16	73 ± 2	2.7
chiffon, 2 layers	83 ± 9	90 ± 1	3.0
natural silk, 1 layer	54 ± 8	56 ± 2	2.5
natural silk, 2 layers	65 ± 10	65 ± 2	2.7
natural silk, 4 layers	86 ± 5	88 ± 1	2.7
hybrid 1: cotton/chiffon	97 ± 2	99.2 ± 0.2	3.0
hybrid 2: cotton/silk (no gap)	94 ± 2	98.5 ± 0.2	3.0
hybrid 2: cotton/silk (gap)	37 ± 7	32 ± 3	3.0
hybrid 3: cotton/flannel	95 ± 2	96 ± 1	3.0

[a]The filtration efficiencies are the weighted averages for each size range—less than 300 nm and more than 300 nm.

presence of gaps between the mask and the facial contours will result in "leakage" reducing the effectiveness of the masks. It is well recognized that the "fit" is a critical aspect of a high-performance mask.[27,28,33,41] Earlier researchers have attempted to examine this qualitatively in cloth and other masks through feedback on "fit" from human trials.[11,12] In our case, we have made a preliminary examination of this effect *via* the use of cross-drilled holes on the tube holding the mask material (see Figure 1) that represents leakage of air. For example, in Figure 4b, we compare the performance of the surgical mask and the cotton/silk hybrid sample with and without a hole that represents about ~1% of the mask area. Whereas the surgical mask provides moderate (>60%) and excellent (close to 100%) particle exclusion below and above 300 nm, respectively, the tests carried out with the 1% opening surprisingly resulted in significant drops in the mask efficiencies across the entire size range (60% drop in the >300 nm range). In this case, the two holes were ~0.635 cm in diameter and the mask area was ~59 cm^2. Similar trends in efficiency drops are seen in the cotton/silk hybrid sample, as well. Hole size also had an influence on the filtration efficiency. In the case of an N95 mask, increasing hole size from 0.5 to 2% of the cloth sample area reduced the weighted average filtration efficiency from ~60 to 50% for a particle of size <300 nm. It is unclear at this point whether specific aerodynamic effects exacerbate the "leakage" effects when simulated by holes. Its determination is outside the scope of this paper. However, our measurements at both the high flow (3.2 CFM) and low flow (1.2 CFM) rates show substantial drop in effectiveness when holes are present. The results in Figures 2−4 highlight materials with good performance. Several fabrics were tested that did not provide strong filtration protection (<30%), and examples include satin and synthetic silk (Table S1). The filtration efficiencies of all of the samples that we measured at both 1.2 CFM and 3.2 CFM are detailed in the Supporting Information (Figures S2−S4).

In Table 1, we summarize the key findings from the various fabrics and approaches that we find promising. Average filtration efficiencies (see Materials and Methods section for further detail) in the 10−178 nm and 300 nm to 6 μm range are presented along with the differential pressures measured across the cloths, which represents the breathability and degree of comfort of the masks. The average differential pressure across all of the fabrics at a flow rate of 1.2 CFM was found to be 2.5 ± 0.4 Pa, indicating a low resistance and represent conditions for good breathability (Table 1).[31] As expected, we observed an increase in the average differential pressures for the higher flow rate (3.2 CFM) case (Table S1).

Guidance. We highlight a few observations from our studies for cloth mask design:

Fabric with tight weaves and low porosity, such as those found in cotton sheets with high thread count, are preferable. For instance, a 600 TPI cotton performed better than an 80 TPI cotton. Fabrics that are porous should be avoided.

Materials such as natural silk, a chiffon weave (we tested a 90% polyester−10% Spandex fabric), and flannel (we tested a 65% cotton−35% polyester blend) can likely provide good electrostatic filtering of particles. We found that four layers of silk (as maybe the case for a wrapped scarf) provided good protection across the 10 nm to 6 μm range of particulates.

Combining layers to form hybrid masks, leveraging mechanical and electrostatic filtering may be an effective approach. This could include high thread count cotton combined with two layers of natural silk or chiffon, for instance. A quilt consisting of two layers of cotton sandwiching a cotton−polyester batting also worked well. In all of these cases, the filtration efficiency was >80% for <300 nm and >90% for >300 nm sized particles.

The filtration properties noted in (i) through (iii) pertain to the intrinsic properties of the mask material and do not take into account the effect of air leaks that arise due to improper

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"fit" of a mask on the user's face. It is critically important that cloth mask designs also take into account the quality of this "fit" to minimize leakage of air between the mask and the contours of the face, while still allowing the exhaled air to be vented effectively. Such leakage can significantly reduce mask effectiveness and are a reason why properly worn N95 masks and masks with elastomeric fittings work so well.

CONCLUSIONS

In conclusion, we have measured the filtration efficiencies of various commonly available fabrics for use as cloth masks in filtering particles in the significant (for aerosol-based virus transmission) size range of ~10 nm to ~6 μm and have presented filtration efficiency data as a function of aerosol particle size. We find that cotton, natural silk, and chiffon can provide good protection, typically above 50% in the entire 10 nm to 6.0 μm range, provided they have a tight weave. Higher threads per inch cotton with tighter weaves resulted in better filtration efficiencies. For instance, a 600 TPI cotton sheet can provide average filtration efficiencies of 79 ± 23% (in the 10 nm to 300 nm range) and 98.4 ± 0.2% (in the 300 nm to 6 μm range). A cotton quilt with batting provides 96 ± 2% (10 nm to 300 nm) and 96.1 ± 0.3% (300 nm to 6 μm). Likely the highly tangled fibrous nature of the batting aids in the superior performance at small particle sizes. Materials such as silk and chiffon are particularly effective (considering their sheerness) at excluding particles in the nanoscale regime (<~100 nm), likely due to electrostatic effects that result in charge transfer with nanoscale aerosol particles. A four-layer silk (used, for instance, as a scarf) was surprisingly effective with an average efficiency of >85% across the 10 nm −6 μm particle size range. As a result, we found that hybrid combinations of cloths such as high threads-per-inch cotton along with silk, chiffon, or flannel can provide broad filtration coverage across both the nanoscale (<300 nm) and micron scale (300 nm to 6 μm) range, likely due to the combined effects of electrostatic and physical filtering. Finally, it is important to note that openings and gaps (such as those between the mask edge and the facial contours) can degrade the performance. Our findings indicate that leakages around the mask area can degrade efficiencies by ~50% or more, pointing out the importance of "fit". Opportunities for future studies include cloth mask design for better "fit" and the role of factors such as humidity (arising from exhalation) and the role of repeated use and washing of cloth masks. In summary, we find that the use of cloth masks can potentially provide significant protection against the transmission of particles in the aerosol size range.

MATERIALS AND METHODS

Materials. All of the fabrics used as well as the surgical masks and N95 respirators tested are commercially available. We used 15 different types of fabrics. This included different types of cotton (80 and 600 threads per inch), cotton quilt, flannel (65% cotton and 35% polyester), synthetic silk (100% polyester), natural silk, Spandex (52% nylon, 39% polyester, and 9% Spandex), satin (97% polyester and 3% Spandex), chiffon (90% polyester and 10% Spandex), and different polyester and polyester−cotton blends. Specific information on the composition, microstructure, and other parameters can be found in the Supporting Information (Table S2).

Polydisperse Aerosol Generation. A polydisperse, nontoxic NaCl aerosol was generated using a particle generator and introduced into the mixing chamber along with an inlet for air. The aerosol is then mixed in the mixing chamber with the help of a portable fan. The particle generator produces particles sizes in the ranges of 10 nm to 10 μm.

Detection of Aerosol Particles. The particles were sampled both upstream (C_u, before the aerosol passes through the test specimen) and downstream (C_d, after the aerosol passes through the test specimen) for 1 min. The samples collected from the upstream and downstream are separately sent to the two particle sizers to determine a particle concentration (pt/cc). Each sample is tested seven times following the minimum sample size recommended by the American Industrial Hygiene Association exposure assessment sampling guidelines.[42] We observed a significantly lower particle count in the upper size distribution for both of the data sets, that is, for particles greater than 178 nm for the data from the TSI Nanoscan analyzer and greater than 6 μm for the data from TSI OPS analyzer. We exclude the data above these thresholds for all of the studies reported due to the extremely low counts. We categorize our data based on these two particle analyzers—individually the two plots (Figure 2a,b) show two size distributions—particles smaller than 300 nm and particles larger than 300 nm. Two different flow rates of 1.2 CFM (a face velocity of 0.1 m/s) and 3.2 CFM (a face velocity of 0.26 m/s) were used that corresponded to rates observed at rest to moderate activity, respectively. The velocity of the aerosol stream was measured at ~5 cm behind where the test specimen would be mounted using a velocity meter.

Differential Pressure. The differential pressure (ΔP) across the test specimen was measured ~7.5 cm away on either side of the material being tested using a micromanometer. The ΔP value is an estimate of the breathability of the fabric.

Data Analysis. The particle concentrations from seven consecutive measurements were recorded and divided into multiple bins—10 for nanoparticle sizer (dimensions in nm: 10−13, 13−18, 18−24, 24−32, 32−42, 42−56, 56−75, 75−100, 100−133, 133−178) and 6 for optical particle sizer (dimensions in μm: 0.3−0.6, 0.6−1.0, 1.0−2.0, 2.0−3.0, 3.0−4.0, 4.0−6.0). The seven measurements for each bin were subjected to one iteration of the Grubbs' test with a 95% confidence interval to remove at most one outlier per bin. This improves the statistical viability of the data. Following Grubbs' test, average concentrations were used to calculate the filtration efficiencies as described below.

Filtration Efficiency. The filtration efficiency (FE) of different masks was calculated using the following formula:

$$\mathrm{FE} = \frac{C_u - C_d}{C_u}$$

where C_u and C_d are the mean particle concentrations per bin upstream and downstream, respectively. To account for any possible drifts in the aerosol generation, we measured upstream concentrations before and after the downstream measurement and used the average of these two upstream values to calculate C_u (for runs that did not include a gap). We do not measure upstream concentration twice when the run included a gap. The error in FE was calculated using the quadrature rule of error propagation. Due to noise in the measurements, some FE values were below 0, which is unrealistic. As such, negative FE values were removed from consideration in figures and further calculations. In addition to the FE curves, we computed an aggregate filter efficiency for each test specimen. To do this, we took a weighted average of FE values weighted by the bin width for the two particle size ranges (<300 nm and >300 nm). These values are reported in Table 1 and Table S1.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsnano.0c03252.

Filtration efficiencies for various fabrics tested at two different flow rates and the effect of layering on the filtration efficiencies of chiffon, silk, and 600 TPI cotton; detailed information on various fabrics used (PDF)

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Face Masks Against COVID-19: An Evidence Review

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The science around the use of masks by the general public to impede COVID-19 transmission is advancing rapidly. Policymakers need guidance on how masks should be used by the general population to combat the COVID-19 pandemic. Here, we synthesize the relevant literature to inform multiple areas: 1) transmission characteristics of COVID-19, 2) filtering characteristics and efficacy of masks, 3) estimated population impacts of widespread community mask use, and 4) sociological considerations for policies concerning mask-wearing. A primary route of transmission of COVID-19 is likely via small respiratory droplets, and is known to be transmissible from presymptomatic and asymptomatic individuals. Reducing disease spread requires two things: first, limit contacts of infected individuals via physical distancing and contact tracing with appropriate quarantine, and second, reduce the transmission probability per contact by wearing masks in public, among other measures. The preponderance of evidence indicates that mask wearing reduces the transmissibility per contact by reducing transmission of infected droplets in both laboratory and clinical contexts. Public mask wearing is most effective at stopping spread of the virus when compliance is high. The decreased transmissibility could substantially reduce the death toll and economic impact while the cost of the intervention is low. Thus we recommend the adoption of public cloth mask wearing, as an effective form of source control, in conjunction with existing hygiene, distancing, and contact tracing strategies. We recommend that public officials and governments strongly encourage the use of widespread face masks in public, including the use of appropriate regulation.

COVID-19 | SARS-CoV-2 | Masks | Pandemic

Policymakers need urgent guidance on the use of masks by the general population as a tool in combating SARS-CoV-2, the respiratory virus that causes COVID-19. Masks have been recommended as a potential tool to tackle the COVID-19 pandemic since the initial outbreak in China (1), although usage during the outbreak varied by time and province (2). Globally, countries are grappling with translating the evidence of public mask wearing to their contexts. These policies are being developed in a complex decision-making environment, with a novel pandemic, rapid generation of new research, and exponential growth in cases and deaths in many areas. There is currently a global shortage of N95 or FFP2 respirators and surgical masks for use in hospitals. Simple cloth masks present a pragmatic solution for use by the public. This has been supported by the United States and European Centres for Disease Control. We present a literature review on the role of simple cloth masks and policies in reducing COVID-19 transmission.

1. Components to Evaluate for Public Mask Wearing

In order to identify whether public mask wearing is an appropriate policy, we need to consider these questions:

1. Do asymptomatic or presymptomatic patients pose a risk of infecting others?
2. Would a face mask likely decrease the number of people infected by an infectious mask wearer?
3. Are there alternative face covers that will not disrupt the medical supply chain, e.g. homemade cloth masks?
4. Will wearing a mask impact the probability of the wearer becoming infected themselves?
5. Does mask use reduce compliance with other recommended strategies, such as physical distancing and quarantine?

Significance Statement

Governments are evaluating the use of non-medical masks in the community amidst conflicting guidelines from health organizations. This review synthesizes available evidence to provide clarity, and advances the use of the 'precautionary principle' as a key consideration in developing policy around use of non-medical masks in public.

Jeremy Howard prepared the initial literature list; Reshama Shaikh prepared the initial literature summaries; Frederik Questier did additional literature searches and summaries; Zhiyuan Li, Violet Tang, Lei-Han Tang, and Danny Hernandez did impact modeling; Zeynep Tufekci provided sociological research and analysis; Helene-Mari van der Westhuizen and Arne von Delft provided analysis of additional impacts; Christina Bax provided review and feedback; All authors contributed to the writing.

Anne W. Rimoin is an editor of the British Medical Journal. Larry F. Chu is a member of the editorial advisory board of the British Medical Journal.

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6. Are there any other potential benefits to universal mask wearing such as reducing stigma, signaling solidarity, and increased compliance with other measures?

We will evaluate each consideration in turn.

2. Transmission Characteristics of COVID-19

A primary route of transmission of SARS-CoV-2 is likely via small droplets that are ejected when speaking, coughing or sneezing. The most common droplet size threshold has a minimum at 5 µm to 10 µm (3, 4). There is much debate about whether these droplets should sometimes be considered an aerosol (5). An added complexity is that aerosols are not consistently defined in the literature.

Although earlier studies assumed that droplets were spread mainly through coughing, a more recent analysis has found that transmission through talking may be a key vector, with louder speech creating increasing quantities and sizes of droplets, which are associated with a higher viral load (6).

SARS-CoV-2 is highly transmissible, with a replication number estimated to be approximately 2.4 (7) although estimates vary (8) and will likely change as improved measurements of asymptomatic spread become available. Many COVID-19 patients are asymptomatic, and nearly all have a pre-symptomatic incubation period ranging from 2 to 15 days, with a median length of 5.1 days (9). Patients are most infectious during the initial days of infection (10–15), when symptoms are mildest or not present. This characteristic differentiates SARS-CoV-2 (COVID-19) from SARS-CoV, as replication is activated early in the upper respiratory tract (14, 16). High viral titers of SARS-CoV-2 are reported in the saliva of COVID-19 patients. These titers have been highest at time of patient presentation and viral levels are just as high in asymptomatic or presymptomatic patients (11, 16).

A consequence of these disease characteristics is that any successful intervention policy must properly address transmission due to infectious patients that display few or no symptoms and may not realize that they are infected.

3. Filtering Capability of Masks

Masks can be made of different materials and designs (17) which influence their filtering capability. There are rigorous standards evaluating masks used in healthcare settings but these focus on personal protective equipment (PPE) efficacy, that is, the ability of the mask to protect the wearer from infectious particles. N95 (the American standard; the equivalent in Europe is FFP2) respirators are recommended for health workers conducting aerosol-generating procedures during clinical care of COVID-19 patients. While it has been shown that N95 or FFP2 respirators perform well as PPE, they can become a scarce resource during a pandemic. Toner and Waldhorn (2006) (18) point out that shortages of N95 or FFP2 respirators should be anticipated, and say that if no other masks are available, surgical masks, which will provide droplet protection, should be used. One approach that has been studied for handling N95 or FFP2 respirator shortages is sterilization and re-use, which can be effective (19).

Masks can also be used for source control, which refers to blocking droplets ejected by the wearer, as well as PPE. Although we consider both of these as important, our focus in this paper is on source control, because if everyone is wearing masks to decrease the chance that they themselves are unknowingly infecting someone, everyone ends up being more protected.

Multiple studies show the filtration effects of cloth masks relative to surgical masks. Particle sizes for speech are on the order of 1 µm (20) while typical definitions of droplet size are 5 µm-10 µm (5). Generally available household materials had between a 49% and 86% filtration rate for 0.02 µm exhaled particles whereas surgical masks filtered 89% of those particles (21). In a laboratory setting, household materials had 3% to 60% filtration rate for particles in the relevant size range, finding them comparable to some surgical masks (22). In another laboratory setup, a tea cloth mask was found to filter 60% of particles between 0.02 µm to 1 µm, where surgical masks filtered 75% (23). Dato et al (2006) (24), note that "quality commercial masks are not always accessible." They designed and tested a mask made from heavyweight T-shirts, finding that it "offered substantial protection from the challenge aerosol and showed good fit with minimal leakage".Although cloth and surgical masks are primarily targeted towards droplet particles, some evidence suggests they may have a partial effect in reducing viral aerosol shedding (25).

When considering the relevance of these studies of ingress, it's important to note that they are likely to substantially underestimate effectiveness of masks for source control. When someone is breathing, speaking, or coughing, only a tiny amount of what is coming out of their mouths is already in aerosol form. Nearly all of what is being emitted is droplets. Many of these droplets will then evaporate and turn into aerosolized particles that are 3 to 5-fold smaller. The point of wearing a mask as source control is largely to stop this process from occurring, since big droplets dehydrate to smaller aerosol particles that can float for longer in air (26).

Anfinrud et al (6) used laser light-scattering to sensitively detect droplet emission while speaking. Their analysis showed that virtually no droplets were "expelled" with a homemade mask consisting of a washcloth attached with two rubber bands around the head, while significant levels were expelled without a mask. The authors stated that "wearing any kind of cloth mouth cover in public by every person, as well as strict adherence to distancing and handwashing, could significantly decrease the transmission rate and thereby contain the pandemic until a vaccine becomes available."

An important focus of analysis for public mask wearing is droplet source control. This refers to the effectiveness of blocking droplets from an infectious person, particularly during speech, when droplets are expelled at a lower pressure and are not small enough to squeeze through the weave of a cotton mask. Many recommended cloth mask designs also include a layer of paper towel or coffee filter, which could increase filter effectiveness for PPE, but does not appear to be necessary for blocking droplet emission (6, 27, 28).

In summary, there is laboratory-based evidence that household masks have some filtration capacity in the relevant droplet size range, as well some efficacy in blocking droplets and particles from the wearer (26). That is, these masks help people keep their droplets to themselves.

4. Mask Efficacy Studies

Although no randomized controlled trials (RCT) on the use of masks as source control for SARS-CoV-2 has been published, a number of studies have attempted to indirectly estimate the efficacy of masks. Overall, an evidence review (29) finds "moderate certainty evidence shows that the use of handwashing plus masks probably reduces the spread of respiratory viruses."

The most relevant paper (30), with important implications for public mask wearing during the COVID-19 outbreak, is one that compares the efficacy of surgical masks for source control for seasonal coronavirus, influenza, and rhinovirus. With ten participants, the masks were effective at blocking coronavirus droplets of all sizes for every subject. However, masks were far less effective at blocking rhinovirus droplets of any size, or of blocking small influenza droplets. The results suggest that masks may have a significant role in source control for the current coronavirus outbreak. The study did not use COVID-19 patients, and it is not yet known whether seasonal coronavirus behaves the same as SARS-CoV-2; however, they are of the same genus, so similar behavior is likely.

Another relevant (but under-powered, with n=4) study (31) found that a cotton mask blocked 96% (reported as 1.5 log units or about a 36-fold decrease) of viral load on average, at eight inches away from a cough from a patient infected with COVID-19. If this is replicated in larger studies it would be an important result, because it has been shown (32) that "every 10-fold increase in viral load results in 26% more patient deaths" from "acute infections caused by highly pathogenic viruses".

A comparison of homemade and surgical masks for bacterial and viral aerosols (21) observed that "the median-fit factor of the homemade masks was one-half that of the surgical masks. Both masks significantly reduced the number of microorganisms expelled by volunteers, although the surgical mask was 3 times more effective in blocking transmission than the homemade mask." Research focused on aerosol exposure has found all types of masks are at least somewhat effective at protecting the wearer. Van der Sande et al (33) found that "all types of masks reduced aerosol exposure, relatively stable over time, unaffected by duration of wear or type of activity", and concluded that "any type of general mask use is likely to decrease viral exposure and infection risk on a population level, despite imperfect fit and imperfect adherence". Overall however, analysis of particle filtration is likely to underestimate the effectiveness of masks, since the fraction of particles that are emitted as aerosol (vs. droplet) is quite small (26). Analysis of seasonal coronavirus compared to rhinovirus (30) suggests that filtration of COVID-19 may be much more effective, especially for source control.

The importance of using masks for health care workers has been observed (34) in three Chinese hospitals where, in each hospital, medical staff wearing masks (mainly in quarantine areas) had no COVID-19 infections, despite being around COVID-19 patients far more often, whilst other medical staff had 10 or more infections in each of the three hospitals.

Masks seem to be effective for source control in the controlled setting of an airplane. One case report (35) describes a man who flew from China to Toronto and then tested positive for COVID-19. He was wearing a mask during the flight. The 25 people closest to him on plane/flight attendants were tested and all were negative. Nobody has been reported from that flight as getting COVID-19. Another case study involving a masked influenza patient on an airplane (36) found that "wearing a face mask was associated with a decreased risk for influenza acquisition during this long-duration flight".

Guideline development for health worker personal protective equipment have focused on whether surgical masks or N95 respirators should be recommended. Most of the research in this area focuses on influenza. At this point, it is not known to what extent findings from influenza studies apply to COVID-19 filtration. Wilkes et al (37) found that "filtration performance of pleated hydrophobic membrane filters was demonstrated to be markedly greater than that of electrostatic filters." However, even substantial differences in materials and construction do not seem to impact the transmission of droplet-borne viruses in practice, such as a meta-analysis of N95 respirators compared to surgical masks (38) that found "the use of N95 respirators compared with surgical masks is not associated with a lower risk of laboratory-confirmed influenza." Johnson et al (39) showed that "surgical and N95 masks were equally effective in preventing the spread of PCR-detectable influenza". Radonovich et al (40) found in an outpatient setting that "use of N95 respirators, compared with medical masks... resulted in no significant difference in the rates of laboratory-confirmed influenza."

One of the most frequently mentioned papers evaluating the benefits and harms of cloth masks have been by MacIntyre et al (41). Findings have been misinterpreted, and therefore justify detailed discussion here. The authors "caution against the use of cloth masks" for healthcare professionals compared to the use of surgical masks and regular procedures, based on an analysis of transmission in hospitals in Hanoi. We emphasize the setting of the study - health workers using masks to protect themselves against infection. The study compared a "surgical mask" group which received 2 new masks per day, to a "cloth mask" group that received 5 masks for the entire 4 week period and were required to wear the masks all day, to a "control group" which used masks in compliance with existing hospital protocols, which the authors describe as a "very high level of mask use". It is important to note that the authors did not have a "no mask" control group because it was deemed "unethical to ask participants to not wear a mask." The study does not inform policy pertaining to public mask wearing as compared to the absence of masks in a community setting, since there is not a "no mask" group. The results of the study show that the group with a regular supply of new surgical masks each day had significantly lower infection of rhinovirus than the group that wore a limited supply of cloth masks. This paper lends support to the use of clean, surgical masks by medical staff in hospital settings to avoid rhinovirus infection by the wearer, and is consistent with other studies that show cloth masks provide poor filtration for rhinovirus (30). Its implementation does not inform the effect of using cloth masks versus not using masks in a community setting for source control of SARS-CoV-2, which is of the same genus as seasonal coronavirus, which has been found to be effectively filtered by cloth masks in a source control setting (30).

A. Studies of Impact on Community Transmission. When evaluating the available evidence for the impact of masks on community transmission, it is critical to clarify the setting of the research study (health care facility or community), the respiratory illness being evaluated and what reference standard was used (no mask or surgical mask). There are no RCTs that have been done to evaluate the impact of masks on community transmission during a coronavirus pandemic. While there is some evidence from influenza outbreaks, the current global pandemic poses a unique challenge. A review (42) of 67 studies including randomized controlled trials and observational studies found that simple and lowcost interventions would be useful for reducing transmission of epidemic respiratory viruses. The review recommended that "the following effective interventions should be implemented, preferably in a combined fashion, to reduce transmission of viral respiratory disease: 1. frequent handwashing with or without adjunct antiseptics; 2. barrier measures such as gloves, gowns, and masks with filtration apparatus; and 3. suspicion diagnosis with the isolation of likely cases". However, it cautioned that routine longterm implementation of some measures assessed might be difficult without the threat of an epidemic.

Seuess et al conducted an RCT (43)that suggests household transmission of influenza can be reduced by the use of non-pharmaceutical interventions, namely the use of face masks and intensified hand hygiene, when implemented early and used diligently. Concerns about acceptability and tolerability of the interventions should not be a reason against their recommendation (43). Cowling et al (44) investigated hand hygiene and face masks in an RCT that seemed to prevent household transmission of influenza virus when implemented within 36 hours of index patient symptom onset. These findings suggest that non-pharmaceutical interventions are important for mitigation of pandemic and inter-pandemic influenza.

RCT findings by Aiello et al (45) "suggest that face masks and hand hygiene may reduce respiratory illnesses in shared living settings and mitigate the impact of the influenza A (H1N1) pandemic". A randomized intervention trial (46) found that "face masks and hand hygiene combined may reduce the rate of ILI [influenza-like illness] and confirmed influenza in community settings. These non-pharmaceutical measures should be recommended in crowded settings at the start of an influenza pandemic." The authors noted that their study "demonstrated a significant association between the combined use of face masks and hand hygiene and a substantially reduced incidence of ILI during a seasonal influenza outbreak. If masks and hand hygiene have similar impacts on primary incidence of infection with other seasonal and pandemic strains, particularly in crowded, community settings, then transmission of viruses between persons may be significantly decreased by these interventions."

An observational study in Hong Kong on SARS (47) found "frequent mask use in public venues, frequent hand washing, and disinfecting the living quarters were significant protective factors (OR 0.36 to 0.58)". An important observation was that "members of the case group [infected with SARS] were less likely than members of the control group [not infected] to have frequently worn a face mask in public venues (27.9% vs. 58.7%)".

B. Implementation and Sociolological Considerations. For a novel disease where much is unknown, it is important to examine the context of studies closely and also distinguish "absence of evidence" from "evidence of absence" (2). We discuss estimates of cloth mask filtering performance in Filtering Capability of Masks and summarize modelling on population impact in Estimating Population Impacts.

Some of the concerns about public mask wearing have not been around primary evidence for the efficacy of source control, but concerns about how they will be used. We present some considerations for the translation of evidence about public mask wearing to diverse countries across the globe, outside of the parameters of a controlled research setting:

B.1. Supply chain management of N95 respirators and surgical masks. There has been a global shortage of protective equipment for health workers, with health workers falling ill and dying of occupationally acquired COVID-19 disease (48). Public messaging encouraging mask use and depleting critical supplies have been a major concern. Some regions, like South Korea and Taiwan, have decided to promote surgical mask use on a mass scale and opted to address potential stock issues through rapidly increasing production of surgical masks. In regions where surgical mask supplies are scarce, cloth masks may be a pragmatic temporary alternative to surgical masks for the public.

B.2. Sociological considerations and anticipating population-level behavior changes. It is difficult to predict the behavior change that would accompany regulations encouraging public mask use. One concern around public health messaging promoting the use of face-covering has been that members of the public may use risk compensation behavior and neglect physical distancing based on overvaluing the protection a surgical mask may offer due to an exaggerated or false sense of security (49). Similar arguments have previously been made for HIV prevention strategies (50) (51) and other safety devices and mandates such as motorcycle helmet laws (52) and seat-belts (53). However, research on these topics finds no such increase in adverse outcomes at the population level but rather improvements in safety and well-being, suggesting that even if risk compensation occurs in some individuals, that effect is dwarfed by the increased safety at the population level (53, 54). Further, even for deliberately high-risk recreational activities such as alpine skiing and snowboarding, wearing a helmet was generally associated with risk reduction oriented-behavior (55), suggesting safety devices are both compatible with and perhaps encourage safety-oriented behavior. Even for high-risk recreational activities like alpine skiing and snowboarding, helmet use has greatly reduced injury rates (56).

In general, various forms of risk compensation theories have been proposed for many different safety innovations, but have been not found to have empirical support (57) at the population level. These findings strongly suggest that, instead of withholding a preventative tool, accompanying it with accurate messaging that combines different preventative measures would display trust in the general public's ability to act responsibly and empower citizens, and risk compensation is unlikely to undo the positive benefits at the population level (58).

At the height of the 2009 influenza epidemic in Mexico City it was found (59) that mandatory mask requirements increased compliance compared to voluntary recommendations. Voluntary compliance was strongly influenced by public perception regarding the effectiveness of the recommended measures.

For many infectious diseases, including, for example, tuberculosis, health authorities recommend masks only for those infected or people who are taking care of someone infected. However, research shows that many sick people are reluctant to wear a mask if it identifies them as sick, and thus end up not wearing them at all in an effort to avoid the stigma of illness (60, 61). Stigma is a powerful force in human societies, and many illnesses come with stigma for the sick as well as fear of them, and managing the stigma is an important part of the process of controlling epidemics as stigma also leads to people avoiding treatment as well as preventive measures that would "out" their illness (62). Many health authorities have recommended wearing masks for COVID-19 only if people are sick; however, reports of people wearing masks being attacked, shunned and stigmatized have already been observed (63). Having masks worn only by the suspected/confirmed infected also has led to employers in high-risk environments like grocery stores and prisons, and even hospitals, banning employees from wearing one sometimes with the idea that it would scare the customer or the patients (64, 65). Further, in many countries, minorities suffer additional stigma and assumptions of criminality (66). In that vein, black people in the United States have reported that they were reluctant to wear masks in public during this pandemic for fear of being mistaken as criminals (67, 68). Even if it were possible to encourage only infected people to wear masks, given the lack of access to testing in many countries, it is not possible for many people to know for sure if they are infected or not (69). Thus, while this paper has shown the importance of masks for source-control – preventing asymptomatic and presymptomatic people from infecting others – it may not even be possible to have infected/sick people wear masks due to stigma, employer restrictions, or simple lack of knowledge of ones status without mask-wearing becoming universal policy.

Another important benefit of recommending universal mask wearing would be to serve as a visible signal and reminder of the pandemic, and given the importance of ritual and solidarity in human societies (70), it is plausible that visible, public signaling via mask wearing can potentially increase compliance with other health measures as well, such as keeping distance and hand-washing. Health, especially during an epidemic, is a form of public good in that everyone else's health behaviors improve the health odds of everyone else, and that it is non-rivalrous in that one person's health does not diminish the health of anyone else (71, 72). Visible signals play an important role in human societies (73). As such, signaling participation in health behaviors by wearing a mask as well as visible enforcement (for example, shops asking customers to wear masks) can increase compliance (74). Further, historically epidemics are a time of fear, confusion and helplessness (75, 76). Mask-wearing and even mask-making or distribution can provide feelings of empowerment and self-efficacy (77), which would in turn also suggest masks could increase compliance in other health-behaviors as well by increasing self-efficacy. In Hong Kong, for example, a community-driven focus on epidemic prevention started in the early days of COVID-19, and included community activists acquiring and distributing masks especially to those without resources and the elderly, even before it was officially declared a pandemic or before their own government had taken strong steps (78). Currently, Hong Kong has not only a relatively contained epidemic compared with many other countries, but a significant reduction in influenza cases as well which their health authorities attribute, among other factors, to the near-universal mask wearing and strong norms around it (79–81).

C. Universal or near-universal mask wearing. Estimating adherence to regulations for public mask wearing is a key input for modeling the impact of public mask wearing. Telephone surveys during the SARS-CoV-2 outbreak in Hong Kong reported enhanced adherence to public mask wearing as the pandemic progressed over three weeks, with 74.5% self reported mask wearing when going out increasing to 97.5%, without mandatory requirements (82). Similar surveys reported face mask use in Hong Kong during the SARS outbreak in 2003 as 79% (83), and approximately 10% during the influenza A(H1N1) pandemic in 2009 (84). This suggests that the public have enhanced awareness of their risk, and display higher adherence levels to prevention strategies than during other epidemics. Cloth masks could be an additional tool to enhance awareness of the importance of physical distancing in public places, serving as a visual reminder. Should masks be reserved solely for use in symptomatic patients, they become a symbol of illness and could lead to public stigmatization that discourages use, as has been described for patients with tuberculosis (61). Countries like the Czech Republic and Hong Kong offer interesting perspectives on the role of citizen advocacy and on the acceptability of face-covering in public.

D. Balancing potential harm of cloth masks with additional benefits for concurrent epidemic. Based on our detailed discussion above, cloth masks have not been shown to increase the risk of infection in people using them compared to not wearing any mask. While the focus of this article has been on preventing the spread of COVID-19 disease through public mask wearing, many low-middle income countries face concurrent epidemics of diseases like tuberculosis. Tuberculosis kills 1.5 million people globally per year, and in 2018, 10 million people fell ill (85). Face covering has been shown to also reduce the transmission of tuberculosis (86) and offer additional benefits to public mask wearing. Similarly, influenza transmissibility in the community was found to have declined by 44% in Hong Kong after the implementation of changes in population behaviors, including social distancing and increased mask wearing, enforced in most stores, during the COVID-19 outbreak (82).

It has been noted (87) that ensuring compliance with non-pharmaceutical interventions can be challenging: "Mask wearing is a promising non-pharmaceutical intervention to reduce risk of secondary transmission of viral URI [upper respiratory infections], but it is likely that adherence to mask wearing would occur only if there was a major pandemic that resulted in a heightened level of community concern and fear." Many regions have now passed laws to ensure compliance. The first RCT (2008) on mask use (88) "found compliance to be low, but compliance is affected by the perception of risk. In a pandemic, we would expect compliance to improve." The authors noted that "in compliant users, masks were highly efficacious."

5. Estimating Population Impacts

At the national and global scale, effective local interventions are aggregated into epidemiological parameters of disease spread. The standard epidemiological measure of spread is known as the reproduction number R_0 which parameterizes

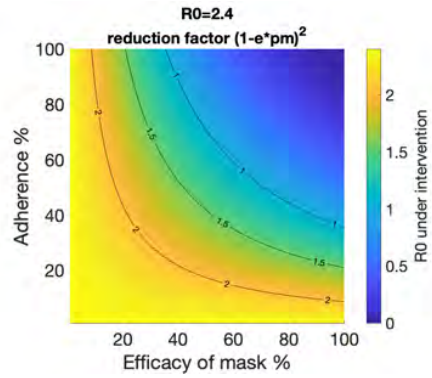

Fig. 1. Impact of public mask wearing under the full range of mask adherence and efficacy scenarios. The color indicates the resulting reproduction number R_0 from an initial R_0 of 2.4 (7).

the number of cases infected by one case,in a completely susceptible population. R_0 determines the rate of growth, with a superlinear effect. The goal of any related healthcare policy is to have an aggregate effect of reducing R_0 to below 1.0.

Efficacy of face masks within local interventions would have an aggregate effect on the reproduction number of the epidemic. What is the magnitude of such an effect? The HKBU COVID-19 Modelling Group developed a transmission model that incorporated mask wearing and mask efficacy as a factor in the model (89). They estimate reductions in the basic reproduction number R_0 under common intervention measures. For wearing masks, they find that wearing masks reduces R_0 by a factor $(1 - ep_m)^2$, where e is the efficacy of trapping viral particles inside the mask, and p_m is the percentage of the population that wears masks. When combined with contact tracing, the two effects multiply.

A conservative assessment applied to the COVID-19 estimated R_0 of 2.4 (7) might posit 50% mask usage and a 50% mask efficacy level, reducing R_0 to 1.35, an order of magnitude impact rendering spread comparable to the reproduction number of seasonal influenza. To put this in perspective, 100 cases at the start of a month becomes 31,280 cases by the month's end ($R_0 = 2.4$) vs. only 584 cases ($R_0 = 1.35$). Such a slowdown in case-load protects healthcare capacity and renders a local epidemic amenable to contact tracing interventions that can eliminate the spread entirely.

A full range of efficacy e and adherence p_m is shown with the resulting R_0 in Figure 1, illustrating regimes in which growth is halted entirely ($R_0 < 1$) as well as pessimistic regimes (e.g. due to poor implementation or population compliance) that nonetheless result in a beneficial effect in suppressing the exponential growth of the pandemic.

Yan et al (90) provide an additional example of an incremental impact assessment of respiratory protective devices using an augmented variant of a traditional SIR model in the context of influenza with N95 respirators. They showed that a sufficiently high adherence rate (~ 80% of the population) resulted in the elimination of the outbreak with most respiratory protective devices.

Qualitative comparisons of outcomes between countries (91, 92) are suggestive of policy differences leading to differences in disease spread of up to three orders of magnitude. Although between-country comparisons do not allow for causal attribution, they suggest mask wearing to be a low-risk measure with a potentially large positive impact, with many countries with widespread use of masks in public keeping deaths below one in a million.

Abaluck et al (93) extend the between-country analyses from a cost perspective, estimating the marginal benefit per cloth mask worn to range from $3,000-$6,000. They also found that "the average daily growth rate of confirmed positives is 18% in countries with no preexisting mask norms and 10% in countries with such norms." and "that the growth rate of deaths is 21% in countries with no mask norms and 11% in countries with such norms."

6. Discussion and Recommendations

Our review of the literature offers evidence in favor of widespread mask use to reduce community transmission: non-medical masks use materials that obstruct droplets of the necessary size; people are most infectious in the initial period post-infection, where it is common to have few or no symptoms (10–16); non-medical masks have been effective in reducing transmission of influenza; non-medical masks have been shown to be effective in small trials at blocking transmission of coronavirus; and places and time periods where mask usage is required or widespread have shown substantially lower community transmission.

The available evidence suggests that near-universal adoption of non-medical masks when out in public, in combination with complementary public health measures could successfully reduce effective-R to below 1.0, thereby stopping community spread. Economic analysis suggests that the impact of mask wearing could be thousands of US dollars saved per person per mask (93).

Interventions to reduce COVID-19 spread should be prioritized in order of their expected multiple on effective R divided by their cost. By this criterion experimentation with and deployment of universal masks look particularly promising. When used in conjunction with widespread testing, contact tracing, quarantining of anyone that may be infected, hand washing, and physical distancing, face masks are a valuable tool to reduce community transmission. All of these measures, through their effect on R_0, have the potential to reduce the period of lockdown required. As governments talk about relaxing lockdowns, keeping transmissions low enough to preserve health care capacity will be critical until a vaccine can be developed. Mask wearing may be critical to preventing a second wave of infections from overwhelming the health care system – further research is urgently needed here.

UNESCO states that "when human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm" (94). This is known as the "precautionary principle". The World Charter for Nature, which was adopted by the UN General Assembly in 1982, was the first international endorsement of the precautionary principle. It was implemented in an international treaty in the 1987 Montreal Protocol. The loss of life and economic destruction that has been seen already from COVID-19 is a "morally unacceptable harm". The positive impact of public mask wearing on this is "scientifically plausible but uncertain". This notion is reflected in Figure 1 - while researchers may reasonably disagree on the magnitude of transmissibility reduction and compliance, seemingly modest benefits can be massively beneficial in the aggregate due to the exponential character of the transmission process. Therefore, the action of ensuring widespread use of masks in the community should be taken, based on this principle (95).

Models suggest that public mask wearing is most effective at stopping spread of the virus when compliance is high. This is the same situation as we see with vaccines - the more people are vaccinated, the higher the benefit to the whole population including those who cannot be vaccinated like infants or immuno-compromised people. A common policy response to this conundrum is to ensure compliance by using laws and regulations, such as widespread state laws in the US which require vaccinations to attend school. Research shows that the strength of the mandate to vaccinate greatly influences compliance rates for vaccines and that policies that set a higher bar for vaccine exemptions result in higher vaccination rates. (96) The same approach is now being used in many jurisdictions to increase mask wearing compliance, by mandating mask use in a variety of settings (such as public transportation or grocery stores or even at all times outside the home). Early results suggest that these laws are effective at increasing compliance and slowing or stopping the spread of COVID-19 (91). We recommend that mask use requirements are implemented by governments, or when governments do not, by organizations that provide public-facing services, such as transit service providers or stores, as "no mask, no service" rules. Such mandates must be accompanied by measures to ensure access to masks, possibly including distribution and rationing mechanisms so that they do not become discriminatory but remain focused on the public health benefit. Given the value of the source control principle, especially for presymptomatic people, it is not good enough for only employees to wear masks, customers must wear masks as well.

It is also important for health authorities to provide clear guidelines for the production, use and sanitization or re-use of face masks, and consider their distribution as shortages allow. A number of countries have distributed surgical masks (South Korea, Taiwan) from early on while Japan and Singapore are now distributing cloth masks to their whole population. Clear and implementable guidelines can help increase compliance, and bring communities closer to the goal of reducing and ultimately stopping the spread of COVID-19.

Materials and Methods

A community-driven approach was used for building the paper list used in this literature review. A multidisciplinary community of researchers used online tools to review and actively discuss publications related to the question of the effectiveness and policy of public mask wearing.

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E HIBIT DDD

New IHME COVID-19 Forecasts See Nearly 300,000 Deaths by December 1, However, Consistent Mask-Wearing Could Save about 70,000 Lives

Riding a 'rollercoaster' of responsibility and recklessness perpetuates infections

Strong results when governments mandate and enforce mask-wearing

NEWS PROVIDED BY
Institute for Health Metrics and Evaluation →
Aug 06, 2020, 13:00 ET

SEATTLE, Aug. 6, 2020 /PRNewswire/ -- America's COVID-19 death toll is expected to reach nearly 300,000 by December 1, however, consistent mask-wearing beginning today could save about 70,000 lives, according to new data from the Institute for Health Metrics and Evaluation (IHME) at the University of Washington's School of Medicine.

The US forecast totals 295,011 deaths by December. As of today when, thus far, 158,000 have died, IHME is projecting approximately more 137,000 deaths. However, starting today if 95% of the people in the US were to wear masks when leaving their homes, that total number would decrease to 228,271 deaths, a drop of 49%. And more than 66,000 lives would be saved.

Masks and other protective measures against transmission of the virus are essential to staying COVID-free, but people's inconsistent use of those measures is a serious problem, said IHME Director Dr. Christopher Murray.

"We're seeing a rollercoaster in the United States," Murray said. "It appears that people are wearing masks and socially distancing more frequently as infections increase, then after a while as infections drop, people let their guard down and stop taking these measures to protect themselves and others – which, of course, leads to more infections. And the potentially deadly cycle starts over again."

Murray noted that there appear to be fewer transmissions of the virus in Arizona, California, Florida, and Texas, but deaths are rising and will continue to rise for the next week or two. The drop in infections appears to be driven by the combination of local mandates for mask use, bar and restaurant closures, and more responsible behavior by the public.

"The public's behavior had a direct correlation to the transmission of the virus and, in turn, the numbers of deaths," Murray said. "Such efforts to act more cautiously and responsibly will be an important aspect of COVID-19 forecasting and the up-and-down patterns in individual states throughout the coming months and into next year."

Murray said that based on cases, hospitalizations, and deaths, several states are seeing increases in the transmission of COVID-19, including Colorado, Idaho, Kansas, Kentucky, Mississippi, Missouri, Ohio, Oklahoma, Oregon and Virginia.

"These states may experience increasing cases for several weeks and then may see a response toward more responsible behavior," Murray said.

In addition, since July 15, several states have added mask mandates. IHME's statistical analysis suggests that mandates with no penalties increase mask wearing by 8 percentage points. But mandates with penalties increase mask wearing by 15 percentage points.

"These efforts, along with media coverage and public information efforts by state and local health agencies and others, have led to an increase in the US rate of mask wearing by about 5 percentage points since mid-July," Murray said.

Mask-wearing increases have been larger in states with larger epidemics, he said.

IHME's model assumes that states will reimpose a series of mandates, including non-essential business closures and stay-at-home orders, when the daily death rate reaches 8 per million. This threshold is based on data regarding when states and/or communities imposed mandates in March and April, and implies that many states will have to reimpose mandates.

As a result, the model suggests which states will need to reimpose mandates and when:

- August – Arizona, Florida, Mississippi, and South Carolina
- September – Georgia and Texas
- October – Colorado, Kansas, Louisiana, Missouri, Nevada, North Carolina, Oregon, and Washington.
- November – Alabama, Arkansas, California, Iowa, New Mexico, Oklahoma, Utah, and Wisconsin.

However, if mask use is increased to 95%, the re-imposition of stricter mandates could be delayed 6 to 8 weeks on average.

The model also assumes that that 50% of school districts in each state will opt for online instruction only for the 2020–2021 school year.

"As data emerge on actual school patterns, we will incorporate them into our future revisions of forecasts," Murray said. "We recognize that, given mask wearing, the likely restrictions on after-school activities, and the potential for some parents to avoid engaging in school-related functions, our estimated impact of school openings may be overly pessimistic."

The new death projections and other information, such as hospital resources usage, are available at https://covid19.healthdata.org.

IHME wishes to warmly acknowledge the support of these and others who have made our COVID-19 estimation efforts possible.

About the Institute for Health Metrics and Evaluation
The Institute for Health Metrics and Evaluation (IHME) is an independent global health research organization at the University of Washington School of Medicine that provides rigorous and comparable measurement of the world's most important health problems and evaluates the strategies used to address them. IHME is committed to transparency and makes this information widely available so that policymakers have the evidence they need to make informed decisions on allocating resources to improve population health.

SOURCE Institute for Health Metrics and Evaluation

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http://www.healthdata.org/

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E HIBIT EEE

HEALTH (/HEALTH/)

Healthy Living

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State-by-State Guide to Face Mask Requirements

34 states now mandate face-covering in public as Mississippi joins list

by Andy Markowitz, **AARP (https://www.aarp.org)**, Updated August 13, 2020 | Comments: 13

BRAULIO JATAR/SOPA IMAGES/ZUMA WIRE/ALAMY LIVE NEWS

En español (/espanol/salud/vida-saludable/info-2020/uso-de-mascarillas-por-estado-covid.html?intcmp=AE-HLTH-TOSPA-TOGL-ES)

- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- District of Columbia
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky

- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota

- Ohio
- Oklahoma

Mississippi came under a statewide mask mandate Aug. 4, becoming the 34th state to require people to wear face coverings in public to curb the spread of COVID-19. The District of Columbia and Puerto Rico also have mask orders in place.

State mandates vary in details (for example, exemptions for children range in cutoff age from 2 to 12), but broadly speaking, they require masks in indoor public spaces such as restaurants and stores, on public transit and ride-hailing services, and outdoors when unable to maintain 6 feet of distance from others.

There are generally exceptions for people with disabilities or medical conditions that prevent the use of face coverings, and allowances for certain situations where masking is difficult, unnecessary or hinders communication (for example, when swimming, eating, exercising alone, getting dental treatment or speaking with a hearing-impaired person). Some state rules also include exemptions for people attending religious services.

Here's where each state stands on the use of face masks as of Aug. 13.

For the latest coronavirus news and advice go to AARP.org/coronavirus (/coronavirus/).

Alabama

Statewide order: Yes

The state's mask order took effect July 16 and will now run through at least Aug. 31 following an extension by Gov. Kay Ivey. It covers people over age 6 in all indoor public spaces, and in public areas outdoors where 10 or more people are gathered. The updated order also mandates masks for students in second grade and up when schools reopen.

Learn more: Read Alabama's updated mask order (http://alabamapublichealth.gov/legal/assets/order-adph-cov-gatherings-072920.pdf).

Alaska

Statewide order: No

Alaska's Department of Health Social Services "strongly encourages the wearing of masks in public," but the state has not required it. Anchorage, Alaska's largest city, has a mask mandate.

Learn more: Read the Alaska health department's mask guidance (http://dhss.alaska.gov/dph/Epi/id/Pages/COVID-19/coveryourface.aspx).

Arizona

Statewide order: No

Masks are required for employees and customers of barbers and cosmetologists. They are recommended in other circumstances. Several major cities have instituted mask orders.

Learn more: Link to orders on business reopening and public health are on the Arizona Department of Health Services' COVID-19 emergency response (https://www.azdhs.gov/preparedness/epidemiology-disease-control/infectious-disease-epidemiology/index.php#novel-coronavirus-what-everyone-needs) page.

Arkansas

Statewide order: Yes

Gov. Asa Hutchinson announced a statewide mask mandate at a July 16 press briefing. The order, which took effect July 20, exempts children under the age of 10.

Learn more: Read Arkansas' mask order (https://governor.arkansas.gov/images/uploads/executiveOrders/EO_20-43.pdf).

California

Statewide order: Yes

Californians have been required since June 18 to mask up in "most settings outside the home." The policy was updated June 29 to exempt children under age 2.

Learn more: Read the California Department of Public Health's guidance for using face coverings (https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/COVID-19/Guidance-for-Face-Coverings_06-18-2020.pdf).

Colorado

Statewide order: Yes

Gov. Jared Polis' order requires Coloradans over the age of 10 to wear face coverings in indoor public spaces. It took effect July 17 and will be in force for at least 30 days. Counties may be able to opt out if they meet state benchmarks for declining caseloads and several other public health criteria.

Learn more: Read Colorado's mask order (https://www.colorado.gov/governor/sites/default/files/inline-files/D%202020%20138%20Mask%20Order.pdf).

Connecticut

Statewide order: Yes

Gov. Ned Lamont's mask order issued April 17 remains in force. It requires a mask or face covering for “any person in a public place in Connecticut who is unable to or does not maintain a safe social distance of approximately six feet from every other person.” It does not cover children under age 2, or children generally when they are in a child-care setting.

Learn more: Read Connecticut's mask order (https://portal.ct.gov/-/media/Office-of-the-Governor/Executive-Orders/Lamont-Executive-Orders/Executive-Order-No-7BB.pdf?la=en).

Delaware

Statewide order: Yes

A state-of-emergency declaration by Gov. John Carney requires Delawareans over age 12 to “wear face coverings in public settings.” Masks are recommended but not required for children ages 2 to 12.

Learn more: Read Delaware's guidance for face coverings (https://coronavirus.delaware.gov/guidance-for-face-coverings/).

District of Columbia

Citywide order: Yes

People are required to wear masks when they leave home and “are likely to come into contact with another person” under Mayor Muriel Bowser’s July 22 order, which expanded an existing mask mandate. The new version lowers the exemption age from 9 to 2; extends the rule to common areas of apartment and condo complexes; and requires all businesses to deny entry to people without masks.

Learn more: Read the District’s mask order (https://coronavirus.dc.gov/maskorder).

Florida

Statewide order: No

Florida recommends but does not require face coverings for the general public. Several cities and large counties, including Miami-Dade, Palm Beach and Hillsborough (which includes Tampa), have mask requirements.

Learn more: Read Florida's public health advisory (https://floridahealthcovid19.gov/wp-content/uploads/2020/06/20200622-SOF-DOH-Public-Health-Advisory.pdf) and COVID-19 response page (https://floridahealthcovid19.gov/).

Georgia

Statewide order: No

Georgians are "strongly encouraged to wear face coverings as practicable" when outside the home. Gov. Brian Kemp signed an executive order July 15 forbidding city and county governments from implementing mask orders.

Learn more: Read Georgia's mask recommendations (https://georgia.gov/covid-19-coronavirus-georgia/covid-19-state-services-georgia/covid-19-wear-cloth-face-mask-public).

Hawaii

Statewide order: Yes

Gov. David Ige's COVID-19 emergency proclamation requires face covering for customers at or waiting to enter a place of business and for employees who have contact with customers or goods.

Learn more: Read Hawaii's updated COVID-19 emergency order (https://governor.hawaii.gov/wp-content/uploads/2020/06/2006097A-ATG_Ninth-Supplementary-Proclamation-COVID-19-distribution-signed.pdf).

Idaho

Statewide order: No

Idaho's capital and largest city, Boise, requires masks in public, as do several other cities. The state's Stay Healthy Guidelines, updated on June 13, recommend that employers "identify how personal use items such as masks, face coverings, and gloves may be required by employees, vendors, and/or patrons."

Learn more: Read Idaho's COVID-19 resource page (https://coronavirus.idaho.gov/).

Illinois

Statewide order: Yes

Anyone who is over the age of 2 and medically able to wear a mask must do so in a public place when unable to maintain 6-foot distancing.

Learn more: Read Illinois' guidance on public mask use (https://www.dph.illinois.gov/covid19/community-guidance/mask-use).

Indiana

Statewide order: Yes

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Gov. Eric Holcomb's order requiring Hoosiers age 8 and up to mask themselves in most public settings took effect July 27 and will run through at least Aug. 26. It also sets detailed mask requirements for reopening schools, with students in grades 3-12 and all adults required to cover their faces when on school property, until further notice.

Learn more: Read Indiana's mask order (https://www.in.gov/gov/files/Executive%20Order%2020-37%20Face%20Covering%20Requirement.pdf).

Iowa

Statewide order: No

State officials have encouraged mask use. Gov. Kim Reynolds' emergency order, most recently updated June 25, does not mention face coverings among its public health provisions. She has said cities and counties do not have the authority to enact mask mandates.

Learn more: Read the Iowa Department of Public Health's guidance on face coverings (https://idph.iowa.gov/Portals/1/userfiles/7/COVID-19%20Guidance%20for%20Cloth%20Face%20Coverings4_6_20.pdf).

Kansas

Statewide order: Yes

Gov. Laura Kelly issued an executive order July 2 requiring face covering in public. It applies to most people over the age of 5. However, a state law passed in June allows Kansas counties to opt out of gubernatorial health directives, and most are not following the mask order.

Learn more: Read Kansas' mask order (https://governor.kansas.gov/wp-content/uploads/2020/07/20200702093130003.pdf).

Kentucky

Statewide order: Yes

Gov. Andy Beshear's July 9 executive order requires face covering for people "in situations that represent a high risk of COVID-19 transmission," including most public settings. The mandate, initially set to expire on Aug. 8, has been extended through at least Sept. 8. Children age 5 and under are exempt.

Learn more: Read Kentucky's mask order (https://governor.ky.gov/attachments/20200709_Executive-Order_State-of-Emergency.pdf).

BACK TO THE TOP

Statue of chef in New Orleans wearing a face mask holding a sign that says

SOPHIA GERMER/BLOOMBERG VIA GETTY IMAGES

A restaurant sign reminds people to wear a mask in New Orleans, Louisiana.

Louisiana

Statewide order: Yes

Public face-covering is required through at least Aug. 28, per a proclamation issued by Gov. John Bel Edwards on July 11 and extended on July 22 and Aug. 4. The mandate does not apply to children under 8 (although it encourages masking those age 2 to 7) and includes an opt-out for parishes with fewer than 100 COVID-19 cases per 100,000 residents.

Learn more: Read Louisiana's mask order (https://gov.louisiana.gov/assets/Proclamations/2020/89-JBE-2020.pdf).

Maine

Statewide order: Yes

An executive order in effect since May 1 requires people to wear face coverings "in public settings where other physical distancing measures are difficult to maintain." Gov. Janet Mills beefed up the order in early July, requiring large stores, restaurants, lodging establishments, and outdoor bars and tasting rooms to enforce the mask rules.

Learn more: Read Maine's mask order (https://www.maine.gov/governor/mills/sites/maine.gov.governor.mills/files/inline-files/An%20Order%20to%20Stay%20Safer%20at%20Home.pdf).

Maryland

Statewide order: Yes

Effective July 31, Marylanders over age 5 must wear masks in all indoor public spaces and outdoors when they are "unable to consistently maintain six feet of distance" from others. The order by Gov. Larry Hogan expands the state's previous mask mandate, in force since April 18, which applied to retail and food-service establishments and had an age cut-off of 9.

Learn more: Read Maryland's mask order (https://governor.maryland.gov/wp-content/uploads/2020/07/Gatherings-10th-AMENDED-7.29.20.pdf).

Massachusetts

Statewide order: Yes

Gov. Charlie Baker's executive order, in effect since May 6, requires face coverings for people over age 2 in any public space "where social distancing is not possible."

Learn more: Read Massachusetts' mask order (https://www.mass.gov/doc/may-1-2020-masks-and-face-coverings/download).

Michigan

Statewide order: Yes

People over age 4 are required to mask up in any indoor public space and in "crowded outdoor spaces," Gov. Gretchen Whitmer's office announced July 10. Her order also requires businesses to refuse entry or service to people who refuse to wear a face covering, with limited exceptions.

Learn more: Read Michigan's mask order (https://content.govdelivery.com/attachments/MIEOG/2020/07/09/file_attachments/149232 202020-145%20Emerg%20order%20-%20Workplace%20safeguards%20-%20re-issue.pdf).

Minnesota

Statewide order: Yes

Gov. Tim Walz's mask order took effect July 25, superseding a prior mandate that applied to employees at stores, restaurants and other consumer-facing businesses. Children age 5 and under are exempt. People are not required to wear a mask when working alone in an office or cubicle with walls above face height when social distancing is maintained, but must keep one handy for interacting with others.

Learn more: Read Minnesota's mask order (https://www.leg.state.mn.us/archive/execorders/20-81.pdf) and a state FAQ on the face covering rules (https://www.health.state.mn.us/diseases/coronavirus/facecoverfaq.html).

Mississippi

Statewide order: Yes

On Aug. 4, Gov. Tate Reeves issued an order for all Mississippians to wear masks at public gatherings and in retail businesses. Much of the population was already covered by mask mandates that had been applied in 37 of state's 82 counties, including its most populous areas, due to high local rates of COVID-19. The statewide order will be in effect for at least two weeks.

Learn more: Read Mississippi's COVID-19 guidance (https://msdh.ms.gov/msdhsite/_static/14,21866,420.html#EO1507).

Missouri

Statewide order: No

The state Department of Health and Senior Services recommends wearing a face covering in public. Gov. Mike Parson has said he does not intend to implement a statewide requirement. Several cities and counties have enacted mask mandates, including Kansas City and St. Louis.

Learn more: Read the Missouri health department's mask guidance (https://health.mo.gov/living/healthcondiseases/communicable/novel-coronavirus/pdf/face-covering-guidance.pdf).

Montana

Statewide order: Yes

Gov. Steve Bullock's July 15 executive order requires masking up in indoor public spaces and at any "organized outdoor activity" where social distancing cannot be maintained, including markets, weddings and parties. The mandate does not apply to children under age 5 or in counties where there are fewer than four confirmed, active cases of COVID-19.

Learn more: Read Montana's mask order (https://covid19.mt.gov/Portals/223/Documents/Mask%20Directive%20FINAL.pdf?ver=2020-07-15-140109-633).

Nebraska

Statewide order: No

Masks are required for both clients and staff at barbershops, salons and other personal-care businesses. They are recommended for restaurant employees and for the general population when in public. The cities of Lincoln and Omaha have enacted broader local orders that require face-covering in most indoor public places.

Learn more: Read the Nebraska health department's COVID-19 guidance (http://dhhs.ne.gov/Documents/COVID-19%20Guidance%20to%20Public%20and%20Testing.pdf) for the public.

Nevada

Statewide order: Yes

Gov. Steve Sisolak instituted a mandatory face-covering policy on June 24, requiring most people over age 9 to wear a mask "in any public space."

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Learn more: Read Nevada's mask order (https://nvhealthresponse.nv.gov/wp-content/uploads/2020/06/Directive-024-Face-Coverings.pdf).

New Hampshire

Statewide order: No

As of Aug. 11, masks are required at "scheduled gatherings of 100 or more people," unless attendees are seated and spaced 6 feet apart. The order does not apply to children under age 2 or K-12 schools. Previous executive orders mandated face-covering for patrons and staff at personal-care businesses and fitness centers (when not actively working out), and for staff at several other types of businesses, including stores and dining establishments. Otherwise, masks are recommended for the general public when outside the home.

Learn more: Read the New Hampshire public health agency's mask recommendations (https://www.dhhs.nh.gov/dphs/cdcs/covid19/covid-mask-guidance.pdf) and Gov. Chris Sununu's mask order for large gatherings (https://www.governor.nh.gov/sites/g/files/ehbemt336/files/documents/emergency-order-63.pdf)..

New Jersey

Statewide order: Yes

Gov. Phil Murphy's executive order of July 8 mandates face covering in indoor and outdoor public spaces for anyone over age 2. Separate state orders require construction and agricultural workers to wear masks on the job.

Learn more: Read New Jersey's mask order (https://nj.gov/infobank/eo/056murphy/pdf/EO-163.pdf).

New Mexico

Statewide order: Yes

New Mexico has had a mask requirement in place since May 16. Unlike in most states, it applies to people while exercising in gyms, a restriction Gov. Michelle Lujan Grisham added in July. She has ordered that the state "aggressively enforce" the rule, with violators subject to a $100 fine and retailers required to ensure customers are wearing masks.

Learn more: Read New Mexico's mask order (https://www.governor.state.nm.us/wp-content/uploads/2020/05/05_15_2020_PHO.pdf).

New York

Statewide order: Yes

New York has had a mask requirement since April 17. Gov. Andrew Cuomo's order applies to anyone over age 2 who can "medically tolerate a face covering" when in a public place and unable to maintain social distancing.

Learn more: Read New York's mask order (https://www.governor.ny.gov/news/no-20217-continuing-temporary-suspension-and-modification-laws-relating-disaster-emergency).

North Carolina

Statewide order: Yes

Gov. Roy Cooper added a broad public mask mandate to the state's emergency plan in a June 24 executive order, expanding a prior order that had limited the requirement to staff at personal-care, grooming and tattoo businesses. The rule applies to people over age 2 when in public places.

Learn more: Read North Carolina's mask order (https://files.nc.gov/governor/documents/files/EO147-Phase-2-Extension.pdf).

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North Dakota

Statewide order: No

The state encourages employers to recommend staff and customers wear face coverings where it is difficult to maintain social distancing, but there is no statewide requirement.

Learn more: Read public health protocols for individuals and businesses in the state's ND Smart Restart plan (https://ndresponse.gov/covid-19-resources/covid-19-business-and-employer-resources/nd-smart-restart/nd-smart-restart-protocols).

Ohio

Statewide order: Yes

The state mandate took effect July 23, replacing an alert system in which mask orders were imposed on individual counties deemed to be at high risk for coronavirus spread. Gov. Mike DeWine's directive applies to people age 10 and older when in public indoor spaces and outdoors when unable to maintain 6-foot social distancing.

Learn more: Read a statement from the governor's office announcing the mask order (https://governor.ohio.gov/wps/portal/gov/governor/media/news-and-media/covid19-update-07222020).

Oklahoma

Statewide order: No

Gov. Kevin Stitt, who has tested positive for COVID-19, has called on Oklahomans to wear masks in public but rejected calls for a state mandate. A few cities, including Tulsa, have adopted mask requirements.

Learn more: Read the Oklahoma health department's COVID-19 guidance (https://coronavirus.health.ok.gov/what-you-should-know).

Oregon

Statewide order: Yes

Gov. Kate Brown implemented a state mask rule on July 1, covering indoor public spaces. Two weeks later she expanded the mandate to include public outdoor areas, when at least 6 feet of distance cannot be maintained between others outside of an individual's household. Children under 5 are exempt, but the state recommends face coverings for children as young as 2. Indoor gatherings of more than 10 people are prohibited.

Learn more: Read the Oregon Health Authority face covering guidance (https://sharedsystems.dhsoha.state.or.us/DHSForms/Served/le2288K.pdf).

Pennsylvania

Statewide order: Yes

Pennsylvania's mask mandate took effect July 1 on orders from state Health Secretary Rachel Levine. It requires most people age 2 and up to cover their faces in public places, indoors and out. It expanded a prior order that made masks mandatory for employees and, where relevant, customers at essential businesses.

Learn more: Read Pennsylvania's mask order (https://www.governor.pa.gov/wp-content/uploads/2020/07/20200701-SOH-Universal-Face-Coverings-Order.pdf).

Puerto Rico

Territory-wide order: Yes

Gov. Wanda Vázquez issued a directive on May 26 that requires face-covering "at all times" in public places. She has extended the order multiple times since, most recently on July 16.

Learn more: Read Puerto Rico's latest COVID-19 health order (https://www.fortaleza.pr.gov/content/gobernadora-wanda-v-zquez-garced-emite-orden-ejecutiva-2020-054-que-extiende-el-toque-de) (Spanish).

Rhode Island

Statewide order: Yes

Masks have been mandatory since May 8 under Gov. Gina Raimondo's executive order, which requires face coverings for people over age 2 in retail outlets, and in other public spaces unless they "can easily, continuously, and measurably maintain at least 6 feet of distance from other people."

Learn more: Read Rhode Island's mask order (https://governor.ri.gov/documents/orders/Executive-Order-20-30.pdf).

South Carolina

Statewide order: No

Numerous counties and cities, including Charleston and Columbia, have instituted mask mandates. Gov. Henry McMaster has encouraged masking but says a state requirement would be unenforceable. State guidelines encourage reopening businesses to have employees wear masks, "especially when in settings in which social distancing is not feasible."

Learn more: Read the state Department of Health and Environmental Control's COVID-19 guidelines for businesses (https://scdhec.gov/sites/default/files/media/document/DHEC%20Employer%20Return%20to%20Work%20Guidance_5.5.20.pdf).

South Dakota

Statewide order: No

The South Dakota Department of Health recommends "wearing cloth face coverings in public settings where other social distancing measures are difficult to maintain, especially in areas of significant community-based transmission."

Learn more: Read the state health department's COVID-19 information page (https://doh.sd.gov/news/coronavirus.aspx).

Tennessee

Statewide order: No

An April 28 executive order from Gov. Bill Lee urges people to "wear face coverings in public places," as do state health guidelines. Some jurisdictions have enacted mask mandates, including Nashville and Memphis and their surrounding counties.

Learn more: Read Tennessee's COVID-19 health guidelines (https://www.tn.gov/governor/covid-19/health.html).

Texas

Statewide order: Yes

Gov. Greg Abbott's mask order took effect July 3. Children under 10 are excepted. Counties with 20 or fewer active COVID-19 cases can apply to the state for exemption. About a quarter of the state's 254 counties have received exemptions.

Learn more: Read Texas' mask order. (https://open.texas.gov/uploads/files/organization/opentexas/EO-GA-29-use-of-face-coverings-during-COVID-19-IMAGE-07-02-2020.pdf)

Utah

Statewide order: No

State officials have encouraged face covering and established a program to provide a mask for every Utahn who needs one. In recent weeks, Gov. Gary Herbert has mandated masks in state government facilities and in K-12 schools that open this fall, and he signed on to mask orders for Salt Lake and Summit counties.

Learn more: Read Utah's guidelines for protecting yourself from COVID-19 (https://coronavirus.utah.gov/protect-yourself/).

Vermont

Statewide order: Yes

Gov. Phil Scott's directive, announced July 24, applies to Vermonters age 2 and up whenever they are in pubic settings where "close contact is unavoidable." It took effect Aug. 1 and will be in force through at least Aug. 15.

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Learn more: Read guidelines for individuals and businesses in Vermont's COVID-19 Recovery Resource Center (https://governor.vermont.gov/sites/scott/files/documents/ADDENDUM%202%20TO%20AMENDED%20AND%20RESTATED%20EXECUTIVE%20ORDER%20NO.%2001-20.pdf).

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Man and woman in Arlington, Virginia walk past a mural that says It Will Get Better while wearing a mask.

OLIVIER DOULIERY/AFP VIA GETTY IMAGES

Shoppers are required to wear face masks in Arlington, Virginia.

Virginia

Statewide order: Yes

An executive order issued by Gov. Ralph Northam on May 26 mandates masks for people age 10 and up in "indoor settings to which the public has access." There are exceptions for day-care centers and schools. Employees of essential businesses must wear masks in "customer-facing areas."

Learn more: Read Virginia's mask order (https://www.governor.virginia.gov/media/governorvirginiagov/executive-actions/EO-63-and-Order-Of-Public-Health-Emergency-Five---Requirement-To-Wear-Face-Covering-While-Inside-Buildings.pdf).

Washington

Statewide order: Yes

A state public health order that took effect June 26 requires mask use in indoor public settings and outdoors when 6-foot distancing cannot be maintained, for people age 5 and older. Gov. Jay Inslee's mask directives also mandate that businesses require employees to wear face coverings and deny entry to unmasked customers.

Learn more: Read Washington's Guidance on Cloth Face Coverings (https://www.doh.wa.gov/Portals/1/Documents/1600/coronavirus/ClothFacemasks.pdf).

West Virginia

Statewide order: Yes

Gov. Jim Justice's July 6 order requires people age 9 and up to wear face coverings in confined indoor spaces when unable to adequately social distance, other than at home and when "actively engaged in the consumption of food and/or beverage."

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Learn more: Read West Virginia's mask order (https://governor.wv.gov/Documents/2020%20Executive%20Orders/EO%2050-20.pdf).

Wisconsin

Statewide order: Yes

Gov. Tony Evers's emergency order mandating face-covering statewide took effect Aug. 1. The rule applies to people ages 5 and up in all indoor public settings and in "enclosed spaces" such as park structures and outdoor restaurants. Masks are "strongly recommended" but not generally required outside. The order will be in force through at least Sept. 28.

Learn more: Read Wisconsin's mask order (https://evers.wi.gov/Documents/COVID19/EmO01-FaceCoverings.pdf).

Wyoming

Statewide order: No

Patrons at salons and other personal-care businesses are required to wear masks "as much as possible" while being served. Employees of personal-care firms, gyms, entertainment venues, and restaurants and bars must wear masks if they "come within 6 feet of customers or other staff." Face coverings are recommended for the general public, and local governments are authorized to enact their own restrictions.

Learn more: Read the Wyoming Department of Health's mask recommendations (https://health.wyo.gov/targeted-use-of-personal-face-coverings-recommended-for-wyoming-residents/).

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More on Face Coverings

- 10 biggest chains now mandate masks for shoppers (/health/healthy-living/info-2020/retailers-require-face-masks-coronavirus.html)
- How to make a mask at home (/health/healthy-living/info-2020/making-cloth-face-masks.html)
- How to avoid foggy glasses while wearing a mask (/health/conditions-treatments/info-2020/eyewear-face-masks.html)

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By Wei Lyu and George L. Wehby

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Community Use Of Face Masks And COVID-19: Evidence From A Natural Experiment Of State Mandates In The US

ABSTRACT State policies mandating public or community use of face masks or covers in mitigating the spread of coronavirus disease 2019 (COVID-19) are hotly contested. This study provides evidence from a natural experiment on the effects of state government mandates for face mask use in public issued by fifteen states plus Washington, D.C., between April 8 and May 15, 2020. The research design is an event study examining changes in the daily county-level COVID-19 growth rates between March 31 and May 22, 2020. Mandating face mask use in public is associated with a decline in the daily COVID-19 growth rate by 0.9, 1.1, 1.4, 1.7, and 2.0 percentage points in 1–5, 6–10, 11–15, 16–20, and 21 or more days after state face mask orders were signed, respectively. Estimates suggest that as a result of the implementation of these mandates, more than 200,000 COVID-19 cases were averted by May 22, 2020. The findings suggest that requiring face mask use in public could help in mitigating the spread of COVID-19.

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One of the most contentious issues being debated worldwide in the response to the coronavirus disease 2019 (COVID-19) pandemic is the value of wearing masks or face coverings in public settings.[1] A key factor fueling the debate is the limited direct evidence thus far on how much widespread community use would affect COVID-19 spread. However, there is now substantial evidence of asymptomatic transmission of COVID-19.[2,3] For example, a recent study of antibodies in a sample of customers in grocery stores in New York State reported an infection rate of 14.0 percent by March 29 (projected to represent more than 2.1 million cases), which substantially exceeds the number of confirmed COVID-19 cases.[4] Moreover, all public health authorities call on symptomatic people to wear masks to reduce transmission risk. Even organizations that at the time of our study had not yet recommended widespread community use of face masks for COVID-19 mitigation (that is, everyone without symptoms should use a face mask outside of their home), such as the World Health Organization, strongly recommend that symptomatic individuals wear them.[5] Because mask wearing by infected people can reduce transmission risk, and because of the high proportion of asymptomatic infected individuals and transmissions, there appears to be a strong case for the effectiveness of widespread use of face masks in reducing the spread of COVID-19. However, there is no direct evidence thus far on the magnitude of such effects, especially at a population level.

Researchers have been reviewing evidence from previous randomized controlled trials for other respiratory illnesses, examining mask use and types among people at higher risk of contracting infections (such as health care workers or people in infected households). Systematic reviews and meta-analyses of such studies have provided suggestive, although generally weak, evidence.[6] The estimates from the meta-analyses based on randomized controlled trials suggest declines in transmission risk for influenza or influenza-like illnesses to mask wearers, although estimates are mostly statistically insignificant possibly because of small sample sizes or design limitations, especially those related to assessing compliance.[7–9] There is also a relationship between increased adherence to mask use, specifically, and effectiveness of reducing transmission to mask wearers: In one randomized study of influenza transmission in infected households in Australia, transmission risk for mask wearers was lower with greater adherence.[10] Further, the evidence is mixed from randomized studies on types of masks and risk for influenza-like illness transmission to mask wearers; for example, a recent systematic review and meta-analysis comparing N-95 respirators versus surgical masks found a statistically insignificant decline in influenza risk with N-95 respirators.[11]

Positions on widespread face mask use have differed worldwide but are changing over time. In the US, public health authorities did not recommend widespread face mask use in public at the start of the pandemic. The initially limited evidence on asymptomatic transmission and concern about mask shortages for the health care workforce and people caring for patients contributed to that initial decision. On April 3, 2020, the Centers for Disease Control and Prevention (CDC) issued new guidance advising everyone to wear cloth face covers in public areas where close contact with others is unavoidable, citing new evidence on virus transmission from asymptomatic or presymptomatic people.[12] Guidelines differ between countries, and some, including Germany, France, Italy, Spain, China, and South Korea, have mandated the use of face masks in public.[13–16]

This study adds complementary evidence to the literature on the impacts of widespread community use of face masks on COVID-19 spread from a natural experiment based on whether or not US states had mandated the use of face masks in public for COVID-19 mitigation as of May 2020. Fifteen states plus Washington, D.C., issued mandates for face mask use in public between April 8 and May 15.

We identified the effects of state mandates for the use of face masks in public on the daily COVID-19 growth rate, using an event study that examined the effects over different periods. We considered the impact of mandates for mask use targeted only to employees in some work settings, as opposed to communitywide mandates. This evidence is critical, as states and countries worldwide begin to shift to "reopening" their economies and as foot traffic increases. Mandating the public use of masks has become a socially and politically contentious issue, with multiple protests and even acts of violence directed against masked employees and those asking customers to wear face masks.[17] Face cover recommendations and mandates are part of the current set of measures, following earlier social distancing measures such as school and nonessential business closures, bans on large gatherings, and shelter-in-place orders being considered by states and local governments, especially as regions of the country reopen. For example, during Virginia's phase one reopening, begun May 22, 2020, everyone in the state was required to wear a face mask in public where people congregate.[18] Even though more states have issued such orders since the study was completed, it is critical to provide direct evidence on this question not only for public health authorities and governments but also for educating the public.

Study Data And Methods

DATA We collected information on statewide face cover mandate orders from public data sets on such policies and from searching and reviewing all state orders issued between April 1 and May 21, 2020. Our study focused on state executive orders or directives signed by governors that mandate use. Recommendations or guidelines from state departments of public health were not included, as these largely follow the CDC guidelines and might not necessarily add further information or impact. See online appendix A for a more detailed description of the data sources and measuring of the mandates.[19]

States differ in whether or not they require their citizens to wear face masks (covers) to limit COVID-19 spread. Between April 8 and May 15, governors of fifteen states and the mayor of Washington, D.C., signed orders mandating all individuals who can medically tolerate the wearing of a face mask do so in public settings (for example, public transportation, grocery stores, pharmacies, or other retail stores) where maintaining six feet of "social distance" might not always be practicable. These sixteen jurisdictions also have specific mandates requiring employees in certain professions to wear masks at all times while working.

In addition to these sixteen jurisdictions, twenty additional states have employee-only mandates (but no community mandate) requiring that some employees (for example, close-contact service providers such as in barber shops and nail salons) wear a face mask at all times while providing services. The face mask defined in these orders primarily refers to cloth face coverings or nonmedical masks. The state orders strongly discourage the use of any medical or surgical masks and N-95 respirators, which should be reserved for health care workers and first responders. The orders also clearly specify that the face masks are not a replacement for any other social distancing protocols. More information on dates and links to these state orders are in appendix exhibit A1 and appendices D and E.[19] Fifteen states had not yet issued community or employee mandates when we performed the study.

The main model used publicly available daily county-level data of confirmed COVID-19 cases from March 25 through May 21.[20] The data covered all states plus Washington, D.C., and the analytical sample included 2,930 unique counties plus New York City (five boroughs combined). See appendix A for a more detailed description of COVID-19 data.[19]

STATISTICAL ANALYSIS We employed an event study, which is generally similar to a difference-in-differences design, to examine whether statewide mandates to wear face masks in public affect the spread of COVID-19 based on the state variations noted earlier. This design allowed us to estimate the effects in the context of a natural experiment, comparing the pre-post mandate changes in COVID-19 spread in the states with mandates versus changes in COVID-19 spread in the states that did not pass these mandates, over time. The model also tested whether states issuing these mandates had differential pre-event trends in COVID-19 rates before they were issued. This is a critical assumption of the validity of an event study that must be upheld under testing. In addition, the model allowed us to control for a wide range of time-invariant differences between states and counties, such as population density and socioeconomic and demographic factors, plus time-variant differences between states and counties, such as other mitigation and social distancing policies, in addition to state-level COVID-19 testing rates.

We estimated the effects of face cover mandates on the daily county-level COVID-19 growth rate, which is the difference in the natural log of cumulative COVID-19 cases on a given day minus the natural log of cumulative cases in the prior day, multiplied by 100.[21] This measure gives the daily growth rate in percentage points.

The reference period for estimating the face cover mandate effects was 1–5 days before signing the order. We examined how effects change over five post-event periods: 1–5, 6–10, 11–15, 16–20, and 21 or more days. The model also tested for pre-event trends over the course of 6–10, 11–15, and 16 or more days before signing the mandate. For all counties in the analytical sample, the main model included daily data from March 31 (seven days before the first state signed a face cover mandate) through May 22. The models were estimated by least squares weighted by the county's 2019 population with heteroscedasticity-robust and state-clustered standard errors.

As noted earlier, all of the fifteen states plus Washington, D.C., that mandated face cover use in public also mandated employee mask use. To assess the effects of employee face cover mandates, we employed another event study model that focused solely on the employee face cover mandate as the policy intervention. In this analysis, we excluded the sixteen jurisdictions that enacted both public and employee face cover mandates and focused on the twenty states that enacted an employee-only mandate and the fifteen states with neither a public nor an employee mandate.

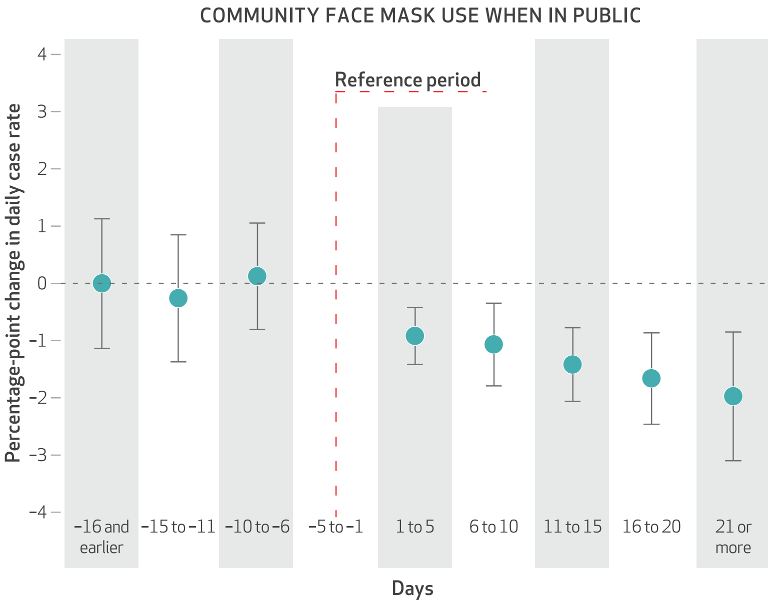
LIMITATIONS We were unable to measure face cover use in the community (that is, compliance with the mandate). As such, the estimates represent the intent-to-treat effects of these mandates—that is, their effects as passed and not the individual-level effect of wearing a face mask in public on one's own COVID-19 risk. Related, we did not measure enforcement of the mandates, which might affect compliance. We also did not have data on county-level mandates for wearing face masks in public. In some states without state-level mandates at the time of our study, such as California,[22] Texas,[23] and Colorado,[24] multiple counties had enacted such mandates. These county-level mandates did not bias the intent-to-treat estimates of effects of state-level mandates as actually passed, but they added local-level heterogeneity not directly accounted for in the model. We did examine the robustness of estimates to the exclusion of some of these states. Finally, we were able to examine only confirmed COVID-19 cases. However, there is evidence of a higher infection rate in the community than is reflected in the number of confirmed cases.[25]

Study Results

EFFECTS OF MANDATES FOR FACE COVERING IN PUBLIC Exhibit 1 plots the event study estimates of effects of state mandates for community face covering in public on the county-level daily growth rate of COVID-19 cases, with 95 percent confidence intervals, obtained from the main regression model (in appendix B),[19] using county-level daily data from March 31 through May22; appendix exhibit C1 (column 1) reports the exact estimates. The effects are shown over the course of five periods after signing the orders, relative to the five days before signing (which is the reference period). Also shown

EXHIBIT 1

Event study estimates of the effects of states mandating community face mask use in public on the daily county-level growth rate of COVID-19 cases, 2020



SOURCE Authors' analysis of US county-level COVID-19 case data between March 31 and May 22, 2020. **NOTES** Event study estimates (dots) and 95% confidence intervals (bars) of the effects of states mandating community use of face covers or masks when people are in public on the county-level daily growth rate of COVID-19 cases over different periods before and after the mandate order was signed. The reference period was the first five days before the mandate order was signed. The model controlled for major COVID-19 mitigation policies as time-varying (closure of K–12 schools, county-level or statewide shelter-in-place orders, nonessential business closure, closure of restaurants for dining in, closure of gyms or movie theaters), COVID-19 tests per 100,000 people, county fixed effects, and day fixed effects. The model was estimated by least squares weighted by the county 2019 population, and the standard errors were robust to heteroscedasticity and clustered at the state level.

are estimated differences in daily COVID-19 growth rates between states with and without the mandates over the course of three periods before the reference period.

There was a significant decline in daily COVID-19 growth rate after the mandating of face covers in public, with the effect increasing over time after the orders were signed. Specifically, the daily case rate declined by 0.9, 1.1, 1.4, 1.7, and 2.0 percentage points within 1–5, 6–10, 11–15, 16–20, and 21 or more days after signing, respectively. All of these declines were statistically significant ($p < 0.05$ or less). In contrast, the pre-event trends in COVID-19 case growth rates were small and statistically insignificant.

We also projected the number of averted COVID-19 cases with the mandates for face mask use in public by comparing actual cumulative daily cases with daily cases predicted by the model if none of the states had enacted the public face cover mandate at the time they did (see details in appendix B).[19] The main model estimates suggested that because of these mandates, 230,000–450,000 cases may have been averted by May 22. Estimates of averted cases should be viewed cautiously and only as general approximations.

ROBUSTNESS CHECKS We estimated multiple extensions of the main event study model to assess the robustness of estimates to different model specifications and sample choices. These checks started the event study on March 26; added flexible controls for social distancing measures, state reopening measures, employee face mask use mandates, and county-specific time trends; and allowed time trends to vary by sociodemographic indicators. Other checks used the mandate effective date instead of the signing date, used hyperbolic sine transformation to account for zero cases, included states as the unit instead of counties, included only urban counties, and excluded some states without state-level mandates but with multiple counties having local mandates. The detailed description and results of these robustness checks are in appendix C.[19] The results were robust across these checks; effects were smaller when we used the effective dates instead of the signing dates, which differ by about two to three days, on average, suggesting earlier compliance, and when we used states as the unit of analysis. But the estimates remained meaningful and statistically significant in all checks.

EFFECTS OF EMPLOYEE-ONLY FACE COVER MANDATES As noted earlier, we also directly assessed the effects of states mandating only that certain employees wear face masks. Twenty states issued employee use mandates but not community use mandates. We reestimated the event study model described earlier for an employee-only mandate including those twenty states (issued between April 17 and May 9) and the fifteen states without mandates, and excluding the sixteen jurisdictions that issued both public and employee use mandates. Exhibit 2 plots the event study estimates of changes in county-level daily COVID-19 growth rates with the employee-only face cover mandates and their 95 percent confidence intervals. All pre- and postmandate estimates were small and insignificant. Overall, these results indicate no evidence of declines in daily COVID-19 growth rates with employee-only mandates.

Discussion

Around the world, governments have been fighting COVID-19 spread through a mix of policies and mitigation measures such as school and nonessential business closures and shelter-in-place orders. Some countries have also recommended or mandated widespread community use of face masks as a mitigation measure. However, the effectiveness of this measure is highly debated. The debate and uncertainty are fueled by the limited direct empirical evidence available on the magnitude of the effects of widespread face mask use in public on COVID-19 mitigation. There is a critical need for empirical evidence on the magnitude of these effects from natural experiments.[8] This evidence is especially relevant as governments reopen their economies and loosen social distancing restrictions while new infections continue to occur and while there is no vaccine or widely accessible or effective treatments in sight.

The study provides direct evidence on the effectiveness of widespread community use of face masks from a natural experiment that evaluated the effects of state government mandates in the US for face mask use in public on COVID-19 spread. Fifteen states plus Washington, D.C., mandated face mask use between April 8 and May 15. Using an event study that examined daily changes in county-level COVID-19 growth rates, the study found that mandating public use of face masks was associated with a reduction in the COVID-19 daily growth rate. Specifically, we found that the average daily county-level growth rate decreases by 0.9, 1.1, 1.4, 1.7, and 2.0 percentage points in 1–5, 6–10, 11–15, 16–20, and 21 or more days after signing, respectively.

These estimates are not small; they represent nearly 16 percent to 19 percent of the effects of other social distancing measures (school closures; bans on large gatherings; shelter-in-place orders; and closures of restaurants, bars, and entertainment venues) after similar periods from their enactment.[21] The estimates suggest that the effectiveness of and benefits from these mandates increase over time. By May 22, 2020, the estimates suggest that 230,000–450,000 COVID-19 cases may have been averted on the basis of when states passed these mandates. Again, the estimates of averted cases should be viewed cautiously, as they are sensitive to assumptions and different approaches to transforming the changes in the daily growth rate estimates to cases.

The early declines in the daily growth rate over the course of five days after signing the order are broadly consistent with the timing of the effects of other social distancing measures such as business closures.[21] Although the median incubation period is estimated to be around five days,[26] there is a wide range from 2.2 days (2.5th percentile) to 11.5 days (97.5th percentile), which suggests that for many people, symptoms may appear relatively early. Further, people may become aware of the mandates early through governors' briefings and related media reports, or they may be anticipating them.

EXHIBIT 2

Event study estimates of effects of states mandating only employee use of face masks during working time on daily county-level growth rate of COVID-19 cases

SOURCE Authors' analysis of US county-level COVID-19 case data between March 31 and May 22, 2020. **NOTES** Event study estimates (dots) and 95% confidence intervals (bars) of the effects of states mandating employee use of face covers or masks on the county-level daily growth rate of COVID-19 cases over different periods before and after the mandate order was signed. This model excluded fifteen states plus Washington, D.C., that made the use of face covering mandatory for both the general public and employees. The reference period was the first five days before the mandate order was signed. The model controlled for major COVID-19 mitigation policies as time-varying (closure of K–12 schools, county-level or statewide shelter-in-place orders, nonessential business closure, closure of restaurants for dining in, and closure of gyms or movie theaters), COVID-19 tests per 100,000 people, county fixed effects, and day fixed effects. The model was estimated by least squares weighted by the county 2019 population, and the standard errors were robust to heteroscedasticity and clustered at state level.

There is no evidence of differential premandate COVID-19 trends with respect to issuing these mandates. The estimates represent the intent-to-treat effects of the statewide face cover mandates as passed, conditional on other national and local measures. In that way, the effects are independent of the CDC national guidance to wear face masks that was issued April 3, 2020.[12] These effects were robust to several model checks. The study provides evidence from a natural experiment on the effectiveness of mandating public use of face masks in mitigating the spread of COVID-19. We found no evidence for effects of states mandating employee face mask use, perhaps because many businesses themselves already required their employees to wear masks.[27,28] In that case, mandating employee mask use reinforce what many businesses already choose to do on their own.

Although the intent-to-treat estimates are of interest for understanding the effectiveness of these policies in limiting COVID-19 spread at the community and population levels, understanding how their effects change with compliance and enforcement strategies is important for designing effective policies. Our study has built the first step in estimating the overall effect of these policies as enacted. However, these policies vary in their strictness and the consequences of noncompliance. The mandates generally require wearing a face mask in public whenever the social distance cannot be maintained. States such as Delaware, Maryland, Massachusetts, and Maine clarify what "public" areas are (for example, indoor space in retail establishments, outdoor space in busy parking lots and waiting areas for take-out services, semi-enclosed areas such as at public transportation stops, and enclosed spaces such as in taxis and other public transportation). The language on enforcement and penalties for noncompliance also vary. In states such as Delaware, Hawaii, Maryland, and Massachusetts, the face mask orders state that they have the force and effect of law, with a willful violation subject to a criminal offense with penalties. For example, the order in Maryland states that "a person who knowingly and willfully violates this order is guilty of a misdemeanor and on conviction is subject to imprisonment not exceeding one year or a fine not exceeding $5,000 or both."[29] In contrast, the orders of other states such as Connecticut, Maine, and Pennsylvania, although clearly mandating the wearing of a face mask in public, do not appear to clearly specify that violations of the order are subject to criminal offense or penalties. Future work should examine whether and how differences in strictness and enforcement modify the effects of these mandates.

Compliance and enforcement may also differ across contextual factors (such as other social distancing measures, workforce distribution, population demographics, and socioeconomic and cultural factors). In that regard, it is important to clarify that the suggested benefits from mandating face mask use are not substitutes for other social distancing measures; the effects are conditional on the other enacted social distancing measures and how communities are complying with them. It is also important to extend the evidence into additional measures of exposure to the virus in the community as data become available, such as from serological testing for antibodies. Finally, future work can examine effects on deaths, which lag cases and change not only with the number of cases but also with case severity.

Conclusion

The study provides evidence that US states mandating the use of face masks in public had a greater decline in daily COVID-19 growth rates after issuing these mandates compared with states that did not issue mandates. These effects were observed conditional on other existing social distancing measures and were independent of the CDC recommendation to wear face covers issued April 3, 2020. As international and state governments begin to relax social distancing restrictions, and considering the high likelihood of a second COVID-19 wave in the fall and winter of 2020,[30] requiring the use of face masks in public could help in reducing COVID-19 spread. ■

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E HIBIT GGG

Association of country-wide coronavirus mortality with demographics, testing, lockdowns, and public wearing of masks (Update August 4, 2020).

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Abstract.

Purpose. To determine sources of variation between countries in per-capita mortality from COVID-19 (caused by the SARS-CoV-2 virus).

Methods. Potential predictors of per-capita coronavirus-related mortality in 200 countries by May 9, 2020 were examined, including age, sex, obesity prevalence, temperature, urbanization, smoking, duration of infection, lockdowns, viral testing, contact tracing policies, and public mask-wearing norms and policies. Multivariable linear regression analysis was performed.

Results. In univariate analyses, the prevalence of smoking, per-capita gross domestic product, urbanization, and colder average country temperature were positively associated with coronavirus-related mortality. In a multivariable analysis of 196 countries, the duration of infection in the country, and the proportion of the population 60 years of age or older were positively associated with per-capita mortality, while duration of mask-wearing by the public was negatively associated with mortality (all p<0.001). International travel restrictions and a lower prevalence of obesity were independently associated with mortality in a model which controlled for testing policy. Internal lockdown requirements and viral testing policies and levels were not associated with mortality. The association of contact tracing policy with mortality approached statistical significance (p=0.06). In countries with cultural norms or government policies supporting public mask-wearing, per-capita coronavirus mortality increased on average by just 15.8% each week, as compared with 62.1% each week in remaining countries.

Conclusions. Societal norms and government policies supporting the wearing of masks by the public, as well as international travel controls, are independently associated with lower per-capita mortality from COVID-19.

Introduction.

The COVID-19 global pandemic caused by infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has presented a major public health challenge. For reasons that are not completely understood, the per-capita mortality from COVID-19 varies by several orders of magnitude between countries.[1] Numerous sources of heterogeneity have been hypothesized. Higher mortality has been observed in older populations and in men.[2,3] Patient-level behaviors, such as smoking, might also have an impact.[3] Other potentially relevant factors include economic activity, and environmental variation, such as temperature.[4] More urban settings and increased population density would be expected to enhance viral transmission.[5]

In addition, public health responses to the COVID-19 pandemic may influence per-capita mortality. Various strategies have been implemented, ranging from robust testing programs to lockdown or stay-at-home orders, to mandates regarding social distancing and face mask usage. Practices with theoretical benefit, such as social distancing, stay-at-home orders, and implementation of mandates regarding use of masks in public spaces, must be assessed quickly, as implementation has the potential to reduce morbidity and mortality.

Mask usage by the public is postulated to decrease infection by blocking the spread of respiratory droplets,[1] and was successfully implemented during other coronavirus outbreaks (i.e. SARS and MERS).[6] In the context of the ongoing pandemic, we assessed the impact of masks on per-capita COVID-19-related mortality, controlling for the aforementioned factors. We hypothesized that in countries where mask use was either an accepted cultural norm or favored by government policies on a national level, the per-capita mortality might be reduced, as compared with countries which did not advocate masks.

Methods.

Data acquisition.

In order to be included in the study, countries had to: 1) have coronavirus mortality data listed in the publicly available Worldometer Database on May 9, 2020;[7] 2) have dates of first case and first death reported by the European Centre for Disease Prevention and Control (which did tabulate worldwide data);[8] and 3) have an assessment of viral testing through May 9, 2020 by either: 3a) report on Worldometer of numbers of coronavirus PCR tests performed,[7] or: 3b) testing and lockdown policies graded by the University of Oxford Coronavirus Government Response Tracker.[9,10]

Oxford University defined and scored several composite government response indices. The stringency index was defined in terms of containment policy and public information.[9] The government response index incorporated containment, economic measures, public information, and testing and tracing policies.[9] The containment and health index was defined in terms of containment measures, public information, and testing and tracing policies.[9]

Archived viral testing data for April 2020 were also downloaded.[11] Mean temperature in each country during the pandemic was estimated using the average monthly temperature in the country's largest city from public sources.[12,13]

Online news reports and government statements, including those cited by a previous review[14] and a public database,[15] were searched to identify countries in which the public wore masks early in the outbreak based on tradition, as well as countries in which the national government mandated or recommended mask-wearing by the public before April 16, 2020.

For each country, the population,[16] fraction of the population age 60 years and over, and age 14 and under, male: female ratio per country,[17] surface area,[16,17] gross domestic product per capita,[18] percent urbanization,[16,19] adult smoking prevalence[20-23] and prevalence of adult obesity[24-43] were tabulated. Whether a nation was an isolated political entity on an island was also recorded.

Statistical analysis.

The prevalence of an infectious process undergoing exponential growth (or decay) appears linear over time when graphed on a logarithmic scale.[1] Therefore, we postulated that the logarithm of the country-wide infection prevalence would be linearly related with the duration of the infection in each country. In addition, our analysis postulated that deaths from coronavirus would follow infections with some delay.

On average, the time from infection with the coronavirus to onset of symptoms is 5.1 days,[44] and the time from symptom onset to death is on average 17.8 days.[45] Therefore, the time from infection to death is expected to be 23 days.[1,46] These incubation and mortality times were prespecified.[1,46] Therefore, the date of each country's initial infection was estimated as the earlier of: 5 days before the first reported infection, or 23 days before the first death.[8,11,47] Deaths by May 9, 2020 would typically reflect infections beginning 23 days previously (by April 16). Therefore, we recorded the time from the first infection in a country until April 16. We also recorded the period of the outbreak: 1) from when public mask-wearing was recommended until April 16, 2) from the mandating of international travel restrictions or quarantine until April 16, and 3) from the start of mandated limits on internal activities (e.g. closures of schools or workplaces, limits on public gatherings or internal movement, or stay-at-home orders) until April 16. For countries scored by Oxford University, the Oxford data were used to determine the start of international travel restrictions and lockdowns on internal activity. In addition, we calculated the mean time-weighted score for each lockdown and testing policy as graded by the University of Oxford for the duration of the country's outbreak, from beginning through April 16.[9] For instance, if the school closure score was 1 for half the outbreak and 2 for the other half, then the mean score was 1.5.

Per-capita mortality can be analyzed as a binary outcome (low or high), or as a continuous variable. Each approach has strengths and weaknesses. Analysis of a binary outcome is not unduly influenced by outliers. Countries with extremely low or high mortality are included in the appropriate group, but the exact mortality value does not change the results. Moreover, analysis of a binary outcome facilities clear communication, because one can describe the characteristics of low and high mortality countries.

On the other hand, per-capita mortality is in fact a continuous variable, and the separation of countries just below or just above a threshold value is somewhat arbitrary, or susceptible to chance variation. Analysis of mortality as a continuous variable uses all the information available, and can appropriately model the exponential growth of an infection. We view the binary and continuous analyses as complementary. When one sees that a univariate association is found with both types of analysis, one gains confidence that the association is not an artifact of the analytic method selected.

In univariate analysis, characteristics of countries with above-median per-capita mortality were compared with the remaining (lower mortality) countries by the two-sample t-test using groups.

Significant predictors of per-capita coronavirus mortality in the univariate analysis were analyzed by stepwise backwards multivariable linear regression analysis. The dependent variable was the logarithm (base 10) of per-capita coronavirus-related mortality. Because of the importance relative to public health, the weeks the country spent in lockdown, with international travel restrictions, and using masks, and per-capita testing levels, were retained in the model. In addition, because of their biological plausibility and presumed importance, urbanization, prevalence of obesity, and average ambient temperature were retained in most of the multivariable models presented below. Statistical analysis was performed with xlstat 2020.1 (Addinsoft, New York). An alpha (p value) of 0.05 was deemed to be statistically significant. The study was approved by the Virginia Commonwealth University Office of Research Subjects Protection.

Results.

We studied coronavirus mortality in 200 countries, of which 183 had testing data,[7] 169 had government policies scored by Oxford University,[9] and 152 fell into both categories.

The 100 lower-mortality countries had 0.99 deaths per million population, in contrast with an average of 93.3 deaths per million population in the 100 higher-mortality countries ($p<0.001$, Table 1, Appendix Table A1). The median value was 4.0 deaths per million population.

We assumed that island nations might find it less challenging to isolate and protect their populations. However, 19 of 100 low-mortality countries were isolated on islands, compared with 28 of 100 high-mortality countries ($p=0.18$). Country surface area and population were not associated with coronavirus mortality (Table 1).

Population characteristics.

Countries with older populations suffered higher coronavirus mortality. Countries with low mortality had on average 8.8% of their population over age 60, as compared with 18.2% in the high-mortality countries ($p<0.001$, Table 1). The proportion of the population which was male was not associated with country-wide mortality ($p=0.95$, Table 1). Smoking prevalence was on average 13.7% in low mortality countries and 18.4% in high-mortality countries ($p<0.001$, Table 1). The prevalence of obesity was on average 14.6% in low-mortality countries and 24.0% in high-mortality countries (p<0.001, Table 1).

Temperature.

Colder countries were associated with higher coronavirus mortality in univariate analysis. The mean temperature was 22.2 C (SD 7.6 C) in the low-mortality countries, and 14.1 C (SD 9.1 C) in the high-mortality countries (p<0.001, Table 1).

Economics.

Urbanization was associated with coronavirus mortality in univariate analysis. In low-mortality countries, on average 52% of the population was urban, as compared with 70% of the population in the high-mortality countries (p<0.001, Table 1). Richer countries suffered a higher coronavirus related mortality. The mean GDP per capita was $9,060 in the low-mortality countries, and was $27,140 in the high-mortality countries (Table 1, p<0.001).

Table 1. Characteristics of countries with low and high per-capita coronavirus mortality by May 9, 2020 in 200 countries.

	Mean (SD)		p value
	Low Mortality	High Mortality	
Deaths (per million)	0.99 (1.14)	93.3 (182.7)	<0.001
Deaths (per capita, log)	-6.47 (0.75)	-4.55 (0.64)	<0.001
Duration infection (weeks)	6.51 (2.87)	7.84 (2.31)	<0.001
Duration infection without masks (weeks)	4.74 (2.33)	6.71 (2.34)	<0.001
Time without international travel restrictions (weeks).	1.44 (1.96)	2.62 (2.38)	<0.001
Duration infection without internal lockdown (weeks)	1.79 (1.85)	2.83 (2.08)	<0.001
Temperature, mean (C)	22.2 (7.6)	14.1 (9.1)	<0.001
Urban population (%)	51.5 (22.6)	70.4 (20.0)	<0.001
GDP per capita ($)	9,060 (16,960)	27,140 (27,500)	<0.001
Age 14 & under (% of pop.)	32.4 (9.8)	20.2 (6.6)	<0.001
Age 60 & over (% of pop.)	8.8 (5.3)	18.2 (7.9)	<0.001
Surface area (million km^2)	0.563 (1.13)	0.796 (2.44)	0.39
Population (million)	51.9 (20.0)	24.7 (48.0)	0.19
Prevalence males (%)	50.1 (2.1)	50.2 (4.2)	0.95
Smoking prevalence, adult (%)	13.7 (7.9)	18.4 (7.7)	<0.001
Obesity prevalence, adult (%)	14.6 (9.0)	24.0 (7.3)	<0.001
Tests per cap. (log) by Apr 4	-3.73 (1.20)	-2.65 (0.76)	<0.001
Tests per cap. (log) by Apr 16	-3.09 (0.87)	-2.31 (0.67)	<0.001
Tests per cap. (log) by May 9	-2.76 (0.86)	-1.92 (0.62)	<0.001

Durations run from the estimated date of first infection in the country until 23 days before May 9, 2020 (i.e. April 16), or the stated event (mask recommendation or lockdown). Obesity data available for 196 countries. Testing data available for 135 countries by April 4, 162 countries by April 16, and 183 countries by May 9.

Masks: Early Adoption.

The World Health Organization initially advised against widespread mask wearing by the public, as did the United States CDC.[1,48] The WHO reversed course and recommended masks in public on June 5, 2020.[49]

Despite these initial recommendations, a number of countries did favor mask wear by the public early in their outbreak, and such countries experienced low coronavirus-related mortality (**Table 2**, Table A1, Figure 1).[50-68,S1-S301] It is likely that in Mongolia and Laos, both of which reported no coronavirus-related mortality by May 9, the public began wearing masks before any cases were confirmed in their countries (Table 2). We identified 22 additional countries with recommendations or cultural norms favoring mask-wearing by the public within 20 days of the estimated onset of the country's outbreak:[1] including (beginning with those favoring masks earliest in the course of their outbreak): Japan, the Philippines, Macau, Hong Kong, Sierra Leone, Cambodia, Timor-Leste, Vietnam, Malaysia, Bhutan, Venezuela, Taiwan, Slovakia, St. Kitts and Nevis, South Korea, Indonesia, Brunei, Grenada, Mozambique, Uzbekistan, Thailand, and Malawi (Table 2). The average mortality by May 9 for these 24 early mask-wearing countries was 1.5 per million (SD 2.0). Twenty of the 24 were lower-mortality countries (p=0.001).

An additional 17 countries recommended that the public wear masks within 30 days of the estimated onset of their outbreak: São Tomé and Príncipe, Czechia, Dominica, Bangladesh, Zambia, Chad, Benin, Sudan, El Salvador, Antigua and Barbuda, Myanmar, Bosnia and Herzegovina, Côte d'Ivoire, South Sudan, Kenya, Saint Lucia, and Barbados (Table 2). The average mortality by May 9 for this group was 8.5 per million (SD 12.4).

Table 2. Countries in which masks were widely used by the public or recommended by the government within 31 days of the estimated local onset of the outbreak, by timeliness of mask-wearing.

	Mask Delay (days)	First Case Date	Mortality (per mil.), by May 9.	Comment.
Mongolia	0	Mar. 10	0.0	The public began wearing masks in January.[S183] The mayor of Ulaanbaatar ordered organizations to implement mask-wearing on January 27, 2020.[S184] Public mask wearing was quite common by mid-February when the government encouraged mask usage by denying service on transport for those not wearing masks.[50]
Laos	0	Mar. 24	0.0	Health officials in Laos advised mask-wearing by March 6,[S156] and the public began wearing masks even before any cases were reported in the country.[S157]
Japan	5	Jan. 16	4.8	Public use of masks is traditional.[48] Surveys indicate that 64% of adults habitually wore a mask in Winter.[51] Public masking was manifest by Jan. 16 when the first domestic case was announced.[S144-S146] The government initially recommended masks when in “confined, badly ventilated spaces”.[48] One survey documented mask wear prevalence over 60% by March 14, increasing to over 75% by April 12.[52] In another poll, 62% indicated wearing a mask in public by March 17, 76% by April 13, 81% by April 20, and 86% by May 4, 2020.[53]
Philippines	5	Jan. 30	6.4	Masks were used extensively as early as Jan. 30.[S215] In a poll, 60% indicated wearing a mask in public on Feb. 24, 76% on March 23, and 81% to 84% from March 30 through June 22.[53] Masks were mandated on April 2.
Macau	6	Jan. 22	0.0	Mask use is traditional. By Jan. 23, the government had implemented a mask distribution program for the public.[S169]
Hong Kong	6	Jan. 23[S121]	0.5	Surgical masks were traditionally used, and also were recommended on public transport and in crowded places, on January 24, 2020.[48,S120] Surveys indicated that masks were worn by about 73% in the week of Jan. 21, and by 98% of the public by mid-February, which persisted into May.[S122] In February 2020, 94.8% of pedestrians were observed to wear masks, and 94.1% believed mass masking reduces the chance of community

				outbreak.[54] A poll consistently found that 85% or more wore masks in public between Feb. 25 and June 22, 2020.[53]
Sierra Leone	6	Mar. 31[S236]	2.3	Masks were recommended in public on April 1.[S237] Compliance has been incomplete.[S238]
Cambodia	6	Jan. 27[S44]	0.0	Masks were widely used by the public by January 28.[S45,S46]
Timor-Leste	7	Mar. 21[S270]	0.0	Masks were required in stores and other venues as part of a state of emergency beginning March 28.[S271]
Vietnam	9	Jan. 23	0.0	Masks were widely used by the public by January 27,[S295,S296] and were mandated by the government on March 16. One survey found the prevalence of mask wear consistently from 85-90% from March 12 to April 14.[52] A poll reported 59% wore a mask on March 23, and between 79% and 87% from March 30 to June 8.[53] From March 31 to April 6, 2020, 99.5% of respondents reported using a mask when outside.[55]
Malaysia	10	Jan. 25	3.3	Masks were used by the public by January 30.[S173] A poll reported 55% wore a mask in public on Feb. 24, 69% on Mar. 23, 82% on Apr 6, and 85-88% from May 4 to June 8.[53]
Bhutan	10	Mar. 6[S31]	0.0	On Mar. 11, the Ministry of Health advised wearing of masks in "a crowded place".[S32]
Venezuela	10	Mar. 13[S291]	0.4	The first death was announced on March 26.[S293] President Maduro demonstrated wearing of masks on live television on March 13 (the day the first case was confirmed), and required masks on public transport.[S290,S291] Masks were required in any public space by March 17.[S292,S293]
Taiwan	11	Jan. 21	0.3	Use of masks is traditional. By January 24, Taiwan banned the export of surgical masks.[56,57] By January 27, the government had to limit mask exports and limit sales from pharmacies to those needed for personal use.[S265] On January 28, the government began releasing 6 million masks daily, with each resident able to purchase 3 masks weekly at a set price.[56] A poll consistently found over 80% wore a mask from Feb. 25 to June 22, 2020.[53]
Slovakia	13	Mar. 7	4.8	Masks were mandated in shops and transit on March 15,[S243] and more broadly in public on March 25.[S244]
St. Kitts and Nevis	14	Mar. 24[S223]	0.0	On April 2, Chief Medical Officer Dr. Hazel Laws recommended wearing a mask in public on the grounds that masks could block

				droplets, and viral particles could remain suspended for 3 hours.[S224] The requirement to wear masks in public became mandatory on April 7.[S225]
South Korea	15	Jan. 20	5.0	Use of masks is traditional.[48] The alert level was raised from yellow to orange on Jan. 27.[58] Children were advised to wear masks at school by January 30.[S249] By Feb. 2, mask sales increased 373 times year-over-year.[58] Stores were selling out of masks by February 3.[S250] A superspreader event in mid-February was associated with a religious group which did not use masks at their gatherings.[59] South Korea initially had trouble obtaining enough masks, but at the end of February the government began to control the distribution of masks to the public.[S251] On Feb. 22, the government instructed the wearing of masks in the epidemic area.[58]
Indonesia	15	Mar. 2[S127]	3.5	The first death occurred on March 3.[S128] The public scrambled to buy face masks in early February.[S126] The proportion of Indonesian adults wearing a mask in public was 54% on Feb. 24, 2020, 47% on March 9, 59% on March 23, 71% on March 30, 79% on April 13, 81% on April 20, and from 82%-84% from May 4 to June 9.[53] During March and April, 76% of students indicated that they wore a mask outside the home.[60] Masks were mandated in public on April 5.[S129]
Brunei	18	Mar. 9[S39]	2.3	On March 22, Sultan Hassanal Bolkiah advised the people to wear masks in public.[S40]
Grenada	18	Mar. 21[S110]	0.0	On April 3, the Ministry of Health recommended all wear a mask, which could be purchased at a pharmacy, to "prevent asymptomatic people from transmitting the disease unknowingly".[S111] Masks were mandated outside the home on April 6.[S112]
Mozambique	18	Mar 22[S188]	0.0	Masks were recommended by health authorities on April 4,[S189] and were required on public transport or in gatherings on April 8.[S190]
Uzbekistan	19	Mar. 15[S288]	0.3	The first coronavirus death was on March 29. Masks were mandated on March 25.[S289]
Thailand	20	Jan. 13	0.8	Masks, including N95 masks, were already worn outdoors in early January to combat smog. The Thai government was handing out masks and advising wearing of masks in public to prevent coronavirus by January 28, 2020.[S266-S269] The recommendation of cloth masks for the public was reaffirmed by the

				Ministry of Public Health on March 3, 2020.[61] Enforcement of a mask mandate on public transport began on March 26.[61] One survey reported high mask-wearing: 73% by Feb. 24, 80% by March 23, and between 84 and 89% between March 30 and June 22.[53] During March 2020, another survey found masks were worn "all the time" by 14% of COVID-19 cases and 24% of controls, and "some of the time" by 38% of cases and 15% of controls.[61]
Malawi	20	Apr. 2	0.2	The first death was on April 7.[S171] The public was required to wear masks on April 4.[S172] A survey in Karonga from April 25 to May 23 found that 22% of urban residents and 5% of rural residents wore a mask.[62]
São Tomé and Príncipe	21	Apr. 6[230]	22.8	On April 22, it was announced that masks would be mandatory in public beginning April 24.[63]
Czechia	23	Mar. 1[S70]	25.8	Masks were required in public on March 19.[S71]
Dominica	23	Mar. 22[S73]	0.0	Prime Minister Skerrit and Health Minister McIntyre wore masks during an interview on March 30.[S75] When Dr. Adis King demonstrated mask-wearing to the legislative assembly on April 7, all in attendance wore masks.[S76] President Savarin recommended the wearing of masks in public on April 9.[S74] Others,[S79] including the state epidemiologist,[S80] repeated this recommendation in coming days. On April 21, physician Sam King estimated that 95% of the population was wearing masks in public.[S78] Masks were mandated on public transport on April 25.[S77]
Bangladesh	24	Mar. 8[S18]	1.3	The first death occurred on March 18.[S19] From March 11-19, 2020, when students age 17 to 28 were asked if they were wearing a surgical face mask in public, 53.8% responded "yes" and an additional 6.6% responded "occasionally".[64] A survey from March 29 to April 29 found that 98.7% reported wearing a face mask in crowded places.[65]
Zambia	24	Mar. 18	0.4	The first death was recorded on April 2. On April 4, masks were recommended for the public "at all times" by the Zambian Minister of Health.[S298] This spurred the manufacture of cloth masks.[S299] On April 16, masks were mandated for the public.[S300]
Chad	24	Mar. 19[S52]	1.9	On April 13, the office of the president announced that a mask or suitable alternative (e.g. turban, veil) would be mandatory in

				public on April 14.[66,S53] On April 14, the government had to backtrack on enforcement due to lack of supplies.[S56] Specific penalties for failing to wear a mask in public were announced on May 7.[S54]
Benin	26	Mar. 16[S27]	0.2	Masks were recommended in public on April 6,[S28] mandated on April 7,[S29] and enforced by police beginning April 8.[S30]
Sudan	27	Mar. 12	1.5	The first death occurred on March 12. Masks were dispensed by pharmacists for free in Sudan by March 16.[S261,S262] A survey from March 25 to April 4 of 2336 adults found that 703 (30.1%) had been to a crowded area, and 1153 (49.4%) had worn a mask outside the home in the previous few days.[67]
El Salvador	27	Mar. 18[S89]	2.6	The first death was reported March 31. President Bukele recommended universal mask wear in public on April 4.[S90] Masks were mandated in San Salvador on April 7.[S91] On April 11, the president announced a nationwide mask mandate, effective April 14.[S92]
Antigua and Barbuda	28	Mar. 13[S9]	30.6	Masks were required in all public spaces on April 5.[S10]
Myanmar	28	Mar. 23[S191]	0.1	In Myanmar, the first death occurred on March 31.[S192] A study from March 3-20, 2020 found that 72% of adults were confident they would wear a surgical mask whenever visiting a crowded area.[68] On April 5, the Ministry of Health recommended masks in crowded places, and cited the US CDC recommendation for the use of cloth masks by the public.[S194] On April 7, State Counsellor Daw Aung San Suu Kyi announced that she would make a mask for herself.[S195] By April 16, some regions mandated masks in public.[S196] A survey from May 7-23, 2020 conducted by the Ministry of Health found that 80% of the public wore a mask each time they went out.[S193]
Bosnia and Herzegovina	29	Mar. 5[S33]	31.1	Masks were required in public by March 29.[S34,S35]
Côte d'Ivoire	29	Mar. 11[S140]	0.8	On April 4, senior health officials recommended masks when in public.[66,S141]
South Sudan	29	Apr. 5[S252]	0.0	On April 29, the High Level Task Force approved the use of locally-manufactured cloth masks to be worn in public.[S253]
Kenya	30	Mar. 12[S150]	0.6	The March 12 case had arrived from the U.S. on March 5.[S150] The first death was on March 26, of a man who arrived in Kenya on March

				13.[S151] Masks were mandated in Kenya on public transport on April 2, and more broadly in public on April 4.[S152,S153] A survey in Nairobi published on May 5, 2020 found that 89% had worn a face mask in the previous week, and 73% said they always did so outside the home.[S154]
Saint Lucia	30	Mar. 13[S226]	0.0	Face masks were recommended to be worn when shopping by the chief medical officer on April 7.[S227,S228]
Barbados	30	Mar. 17[S20]	24.4	By April 11, cloth face masks were required when shopping.[S21-S23] Masks were mandatory on buses by May 11.[S24]

The delay was the number of days from the start of the outbreak until masks were recommended by the government or became widespread due to cultural norms. The estimated start of the outbreak was 5 days before the first infection was reported, or 23 days before the first death (whichever was first).

Masks in Asia.

Throughout much of East, South, and Southeast Asia, masks were worn by the public as a preventive measure, rather than a policy implemented after evidence emerged of health system overload (Table 2). The public sometimes implemented masks before government recommendations were issued.

As the country where the pandemic started, China is a noteworthy case of a nation which traditionally has favored mask-wearing by the public for respiratory illnesses, but which did not deploy masks immediately. The first cases in China had begun by December 1, 2019.[69] By the time human-to-human transmission was confirmed on Jan. 20, 2020, many in Beijing were already wearing masks.[S58] The government required masks in public in Wuhan on Jan. 22.[S59] From Jan. 23-25, thirty regions in China mandated masks in public.[58,70] Masks were ordered throughout China when around others in public on Jan. 31.[S60] China suffered a very significant outbreak in Wuhan, but appears not to have experienced the same level of infection in other regions. Surveys indicate that the prevalence of public mask wear in China remained between 82% and 90% between February 24 and June 22.[53] Another survey confirmed mask wear from 80-90% from March 12 to April 14.[52] The reported country-wide per-capita mortality by May 9, 2020 was 3.2 per million population.

For several countries in South or Southeast Asia with mortality lower than in the West, we did not score the country as mask-wearing in the primary analysis until their governments issued recommendations to do so. Nonetheless, there is evidence of significant mask wear by the public before the recommendations in Nepal, India, and Sri Lanka.

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In Nepal, facemasks are commonly seen in urban centers due to air pollution.[71] The first case of COVID-19 in the country was reported on January 13, in a traveler returning from Wuhan.[72] However, no subsequent cases were reported in Nepal until the second week of March.[72] By January 29, all students at some schools were wearing masks.[S198] By February 3, pharmacies were selling out of masks due to increased demand.[S199] With the outbreak, tailors began sewing cloth masks.[71] By February 8, 2020, "a majority" of the public was wearing masks.[S200] The recommendation to wear masks in public became more formalized on March 25.[S201] The Ministry of Health distributed masks to children and elderly in shelters by March 25.[S202] Surveys in Nepal found that 83% of respondents agreed that asymptomatic people should wear masks to prevent COVID-19 infection at the end of March,[72] and 96% agreed with this statement from May 15 to June 20.[73] As of May 9, Nepal reported no coronavirus-related mortality. We used the March 25 recommendation as the date in the mask analysis, but earlier mask use might have forestalled the epidemic in Nepal.

In India, the first case of coronavirus was diagnosed on January 30.[S124] The Health Ministry recommended homemade face masks on April 4, 2020.[S125] However, mask wear was high both before and after the recommendation. According to one poll, masks were worn by 60% of the public from March 12-14, 67% from March 19-21, and then from 73% to 76% between March 26 through April 12.[52] According to another poll, masks were worn by 43% of the public on March 16, 46% on March 20, 65% on March 27, 71% on April 3, 79% on April 10, and 81-84% between April 17 and May 1.[53] A survey conducted in March 2020 found that 75% of the public believed that masks should be worn even by asymptomatic people, and 77% of respondents indicated that the N95 mask was most protective.[74] By May 9, the per-capita mortality was 1.5 per million.

In Sri Lanka, the public immediately bought masks at the end of January when the first cases were identified.[S257] Masks were mandated in public on April 11.[S258] The per-capita mortality by May 9 was 0.4 per million.

Singapore was slower than its Asian neighbors to embrace masks, but when the government shifted course, the public was ready to respond. On March 27, only 27% of respondents indicated that they wore a mask.[53] On April 3, when the government announced that it would no longer discourage mask-wearing by the public, and would instead distribute masks,[S239-S241] 37% indicated that they wore a mask.[53] Mask wearing by the public reached 73% on April 10, 85% on April 17, and 90% on April 24, where it remained through June 19.[53]

Early in the pandemic, masks were noted to be "somewhat common" in Afghanistan.[75] By March 29, 2020, the Taliban had begun distributing masks to the public in areas under their control.[S1]

In March 2020, 78% of Pakistanis in Sargodha were in favor of wearing a mask to prevent coronavirus.[76] Another survey conducted from April 1-12 indicated that 80% of Pakistanis believed the government should mandate mask wearing for adults outside the home.[77] Masks were mandated when in crowded spaces in Pakistan on May 31.[S209]

Masks in the Middle East.

In parts of the Middle East, masks were embraced by the public even before government requirements. In the United Arab Emirates, the first cases were reported on January 29.[S280] By February 29, mask usage had become "more prominent", but the Ministry of Health and Community Protection advised that N95 masks should be reserved for medical personnel treating coronavirus patients, and could cause "respiratory illness" if worn by the public.[S281] Despite this warning, a poll of UAE residents found that masks were worn by 39% of the public on March 18, and 44% on March 25.[53] On March 27, the government followed the people's lead, and mandated masks when indoors.[S282] Subsequently, masks were worn by 63% on April 1 and between 78% and 81% between April 14 and June 17.[53] By May 9, the per-capita mortality was 18.7 per million.

In Saudi Arabia, the first case was announced on March 2.[S231] A poll of Saudi residents found that 35% wore a mask on March 18, 54% on April 1, and 59% on April 14,[53] despite the lack of any official guidance to do so. A different survey conducted from April 2-5, during a period of lockdown, found that 16.9% had worn a mask even without symptoms.[78] Public mask-wearing was recommended by the Saudi government on April 28,[S232] and mandated on May 30.[S233] Mask-wearing reached 63% on May 4, and 72% on June 3.[53] A survey of Saudi nursing students which concluded on June 30 found that 87% had worn a mask when going out in recent days.[79] By May 9, the per-capita mortality was 6.9 per million.

In Lebanon, the first case was reported on February 21.[S159] Masks were popular among the public from mid-March to early April.[S160,S161] Masks were recommended by the health minister on April 25.[S161] By May 9, the per-capita mortality was 3.8 per million.

In March 2020 in Egypt, 76.4% of adults expressed an understanding of the value of wearing a mask in public, but only 36.4% agreed that they actually did so.[80] At this time, the government was not mandating masks, but by March 20, prices of masks had soared, and volunteer organizations were advocating public masking in Egypt.[S87] Masks were mandated in public in Egypt on May 31.[S88]

In Iran, no infections were announced until February 19, when two deaths were reported.[S130] By March 12, satellite imagery demonstrated the digging of mass graves in Qom.[S131] In accord with WHO guidelines, the guidance of the Iranian Health Ministry available on March 24, 2020 advised that the public wear a mask only if symptomatic or caring for the sick (personal communication, Linnea I. Laestadius, June 7, 2020).[14] However, a new guidance which recommended universal masking in gyms, parks, and public transit was issued by the Ministry by March 29,[14] an estimated 62 days after the start of the outbreak (assuming the reported deaths were really the first). A survey conducted from February 25 to April 25 found that 64% of the public reported wearing a mask and gloves in crowded places.[81] By May 9, the reported per-capita mortality in Iran was 78.4 per million, though many, even those within the Iranian government, have questioned the official figures.[82,83,S132]

In Jordan, a study conducted from March 19-21, 2020 found that 39.8% of university students wore a face mask when leaving home.[84] King Abdullah recommended that the public wear masks when shopping on April 27.[S147]

In Yemen, 90% of women wear the niqab, which local doctors believe might reduce transmission of the virus by functioning as a mask.[85] By May 9, the per-capita mortality in Yemen was 0.2 per million.

In Syria, a survey of university students conducted from March 19-21, 2020 found that 52% of respondents indicated that everyone should wear a mask when outside, but that 25% indicated that they did so at least sometimes, and 75% never wore a mask on the street.[86]

Government mandates or recommendations for mask wearing by the public were issued in Kuwait for gatherings by March 23,[14] in Israel on April 1,[S135] and in Bahrain on April 9.[S17]

Masks in Africa.

As noted above, 11 African countries recommended or mandated masks within 31 days of the onset of their outbreak: Sierra Leone, Mozambique, Malawi, São Tomé and Príncipe, Zambia, Chad, Benin, Sudan, Côte d'Ivoire, South Sudan, and Kenya (Table 2). In addition, the public widely sought masks to wear early in the outbreak in Gambia.[S100,S101]

In Ethiopia, 75.7% of chronic disease patients surveyed from March 2-April 10, 2020 agreed that it was important to wear a mask outside the home to prevent infection with coronavirus.[87] A survey from March 20-24 found that 87% of the public believed wearing a mask could prevent spread of the virus, but only 14% had done so in the few days before the survey.[88] Another survey from April 1-15 in southern Ethiopia found that 84% believed that wearing a mask was protective, 160 respondents (36%) had been to a crowded place in recent days, and 129 respondents (29%) had worn a mask when leaving home in recent days.[89] Masks were mandated in public on April 11.[S95] In a survey in that country from April 15-22, 84% believed a mask could provide protection from coronavirus, 137 people (40%) had gone to a crowded place after the onset of the pandemic, and 82 people (24%) had worn a mask outside the home.[90] By May 9, Ethiopia had reported no deaths from coronavirus.

In Cameroon, the first cases of coronavirus were identified on March 6.[91] From March 10-18, a study found that 93.5% of the public viewed the wearing of face masks as protective, and 21.7% had already purchased them.[91] A study in Northern Cameroon conducted from March 1-28 found that only 13% wore a mask outside the home.[92] A survey in Cameroon conducted from April 1 to 25 found that 83.6% reported wearing a mask at gatherings.[93] On April 9, it was announced that masks would be mandatory in public beginning April 13.[66,S47,S48] By May 9, the per-capita mortality was 4.1 per million.

In a city in the Democratic Republic of the Congo not yet affected by the pandemic at the time of a survey conducted from April 17 to May 11, 61% of respondents were aware of the value of wearing a face mask, 27% reported wearing a face mask since the pandemic began, and 65% felt that wearing a face mask was difficult.[94]

In Ghana, a study from March 27-29 of 43 public transport stations found that masks were worn by many people at one station, worn by a few people at 27 stations, and not worn at the remainder.[95] On April 19, 2020, the president of Ghana announced that masks would be required in public.[S107,S108]

Masks were required in public in Nigeria on April 14.[96,S206] A study in Nigeria from May 7 to 18 found that 65% of respondents had worn a mask outside the home in recent days.[97]

In South Africa from April 8-24, 2020, 85.6% of the public agreed that wearing a mask could help to prevent coronavirus infection.[S246] South African health officials recommended mask wear in public on April 10.[S247]

In addition, government mandates or recommendations for mask wearing by the public were issued by April 16 in: Mauritius on March 31;[S178] Tunisia[S274] and Morocco[S187] on April 6; Guinea on April 13;[S114] Gabon on April 15;[63,66] Equatorial Guinea on April 14;[S93] and Libya on April 16.[S164]

Masks in Europe.

Most countries in Europe and North America failed to embrace masks early in their outbreaks, and only adopted mask policies after signs of health system overload became apparent. Only 3 countries in Europe appear to have had government recommendations for the public to wear masks within 31 days of the onset of their outbreak: Slovakia, Czechia, and Bosnia and Herzegovina (Table 2).

The first country in Europe to be strongly affected by the outbreak was Italy, which reported its first cases on January 31, among a family who arrived from China on January 23.[S136] By March 10, doctors in Lombardy indicated that all intensive care beds were taken, and the system did not have enough respirators for the affected.[208X] A poll found that only 26% of Italians wore a mask in public on March 11, but, with the rising health system overload, 59% did so on March 19[53]—at least 53 days from the local onset of the outbreak. Another poll confirms that the prevalence of mask wear exceeded 50% for the first time from March 19-21.[52] Lombardy (April 5) and Tuscany (April 6) required the public to wear masks in early April.[S138] A nationwide mandate to wear masks in shops and public transport was announced on April 28, to take effect on May 4.[S139] Mask wear in public remained between 85% and 89% between April 16 and June 10.[53] By May 9, the per-capita mortality in Italy was 502.7 per million.

The next country to suffer was Spain, which reported its first case on January 31,[S254] and experienced its first death from the virus on February 13.[S255] The prevalence of mask wear among the Spanish public was 5% on March 12, 25% on March 19, 42% on March 25, and 56% on April 8[53]—potentially 72 days after the entry of the virus into the country. Masks were mandated when in transit beginning April 11.[S256] Mask wearing in public had climbed to 65% by April 16, 72% by April 30, and remained between 84% and 87% between May 20 and June 12.[53] According to another survey, the prevalence of mask wear was 50% by March 21, 53% by April 4, and 61% by April 12.[52] The per-capita mortality by May 9 was 566.3 per million.

In France, the first case of coronavirus was reported on January 24,[S97] and the first death on February 14, of a man who arrived from China on January 16.[S98] A poll found on March 10 that only 5% of those in France wore a mask in public.[53] This number increased to 22% on March 27 and 25% on April 3,[53] the day that the Académie Nationale de Médecine announced that masks should be compulsory in public[S99]—at least 72 days into their outbreak. Polls indicated that mask wear among the public climbed to 38% on April 10, 43% on April 17, 56% on May 1, 76% on May 20, and 75% on June 12.[53] Mask wear below 50% in early April was confirmed in another survey.[52] On May 7, it was announced that throughout France, including its overseas departments, masks would be mandatory on transport, starting May 11.[98] By May 9, the per-capita mortality in France was 403.1 per million.

In Germany, the first case of COVID-19 was reported on January 27. The patient had contact with a colleague visiting from China beginning January 19.[S103] By March 30, only 7% of the public reported wearing a mask in public.[53] On March 31, the city of Jena mandated use of masks by the public.[S104] The Robert Koch Institute recommended that the public wear masks on April 1[S105]—at least 70 days from the onset of the outbreak. Masks were worn by 14% of the public on April 6, 17% on April 13, 24% on April 20, 62%-64% from May 4 through June 18.[53] Another survey confirms mask wear at or below 20% in March and early April.[52] All German states had mandates relating to mask wear in public by April 22.[S106] By May 9, the per-capita mortality was 90.1 per million.

In the United Kingdom, the first cases of coronavirus were reported on January 31.[S283] Here, 2% of the population wore a mask by March 20, 11% by April 17, 20% on May 1, and 27% on June 17.[53] Another survey confirms mask wear below 20% from March 12 to April 12.[52] Masks were recommended in England on public transport and in shops on May 11[S284]—over 100 days after the local outbreak onset. On June 4, English authorities announced that masks would be mandatory on public transit, beginning June 15.[S285] By May 9, the per-capita mortality was 465.3 per million.

In the Netherlands, from April 1 to 19, the prevalence of mask wear was approximately 7%.[99] The prime minister announced on May 6, 2020 that beginning June 1, masks would be required on public transport due to their value in situations where social distancing was not possible.[S203]

In Belgium, from April 4 to 19, the prevalence of mask wear increased from about 30 to 37%.[99] The Prime Minister of Belgium announced on April 24 that masks would be mandatory on public transport effective May 4.[S25]

In the Scandinavian countries of Sweden, Norway, Denmark, and Finland, polls repeatedly showed masks to be worn by 10% or less of the population from March 16 through June 9.[53] This low usage occurred despite the fact that the government in Finland began recommending that the public wear masks on April 14.[S96]

In Switzerland, the chief of the Communicable Diseases Department recommended masks on public transport on June 15.[S264] However, a survey released June 18 found that only 6% of Swiss public transport riders did so.[S264]

In Poland, the health minister announced on April 9 that a public mask mandate would go into effect on April 16, and mask vending machines began to be installed.[S216]

In Poland, from April 12-14, 2020, 60.4% of Polish students age 18 to 27 wore a face mask in the previous 7 days.[100] By May 9, the per-capita mortality was 20.7 per million.

The first cases of coronavirus in Russia were reported on January 31, 2020.[S220] In Russia, the prevalence of mask wear among the public was 11% by March 14, 19% by March 21, 36% by March 28, and 57% by April 4[52]—69 days after the estimated start of the outbreak. Mask wearing prevalence had increased to 59% by April 12.[52] On May 11, it was announced that masks would be mandatory in shops and public transport (Time/Russia). By May 9, the per-capita mortality was 12.5 per million.

In Serbia, in April 2020, 60% of the public agreed they were willing to wear a mask during a pandemic, and respondents on average answered 3.25 (SD 1.6) on a 1 to 5 scale when asked if they wore masks, where 4 represented "agree" and 5 represented "strongly agree".[101]

Some additional Western governments mandated or recommended mask-wearing in public by April 16, 2020. By March 29, masks were mandated in indoor public spaces in Slovenia.[S245] In Austria, a mandate to wear masks in shops was announced on March 30, with the expectation that masks would be available by April 1.[S13] In addition, the requirement to wear masks on public transit was announced there on April 6.[S14] Masks were recommended for the public in Bulgaria[S41] and Ukraine[S278,S279] on March 30. In Lithuania, masks were recommended for the public on March 26,[S166] and mandated on April 8.[S167] Government mandates or recommendations for mask wearing by the public were also issued in: Turkey,[S275] and Cyprus[S69] on April 3; Estonia on April 5;[S94] and Luxembourg on April 15.[S168]

Masks in the United States and Canada.

The earliest case of COVID-19 in the United States was a man who returned from China on January 15, 2020, and presented at an urgent care clinic on January 19.[102] In the United States, the prevalence of mask wear in public was 7% on March 2, 5% on March 17, and 17% on March 30.[53] The U.S. C.D.C. began recommending that asymptomatic people wear a mask in public on the evening of April 3[103]—at least 79 days after the virus had entered the country. Subsequently, the prevalence of mask wear was 29% on April 6, 49% on April 13, 58% on April 20, 63% on April 27, 68% on May 26, and 66% on June 8.[53] Another survey found that the prevalence of mask wear was 32% from April 2-4, and 50% from April 9-12.[52] According to another survey, from April 14-20, 36% of U.S. adults always wore a mask outside the home, 32% did so sometimes, and 31% never did.[S286] Mask wearing varied by region. In Vermont, from May 16 to 30, 76% of people entering businesses were observed to wear a mask.[104] On the other hand, in Wisconsin from June 3-9, only 42% of shoppers were observed to wear a mask.[105] By May 9, the per-capita coronavirus-related mortality was 241.8 per million.

In Canada, the prevalence of mask wear was 6% on March 17, and 18% on April 6,[53] when the government announced that masks were now recommended in public.[S49] Uptake was gradual, with mask wearing at 16% on April 13, 31% on April 20, 41% on April 27, 49% on May 26, and 58% on June 11.[53] Another survey confirms mask wear below 30% in March and early April.[52] By May 9, the per-capita coronavirus-related mortality was 124.3 per million.

Masks in Australia.

In Australia, surveys of the public indicated that 10% wore a mask by March 15, which gradually increased to a high point of 27% by April 19, after which use gradually declined to 17% on June 5.[53] Another survey confirms mask wear below 25% in March and early April.[52]

Masks in Latin America and the Caribbean.On April 3, a reporter in Bogotá noted that 90% of the people on the street were wearing face masks.[S63] On April 4, the government of Colombia mandated masks on public transport and shops.[S62-S65]

On April 6, the Minister of Health in Chile announced that masks would be mandatory on public transport starting April 8.[S57] Due to the shortage of medical masks, the public was invited to make their own out of cloth.[S57]

Surveys indicate that in Mexico, the prevalence of public mask wear increased steadily from 17% on March 17 to 37% on April 6, 46% on April 13, 60% on April 20, and 67% on April 27.[53] According to another survey, the prevalence was 31% by March 14, 36% by March 21, 46% by April 4, and 58% by April 9.[52] Although some states had mandated masks, the federal minister leading the coronavirus response refrained from encouraging the public wearing of masks until May 5.[S180,S181] By May 9, the per-capita mortality was 26.0 per million.

Ecuador did not require masks early in their outbreak. The first case of COVID-19 in Ecuador was reported on February 29 in a traveler who had arrived from Spain on February 14.[S83] The first death was reported on March 13.[S84] By April 3, it was noted in Guayaquil that mortuary facilities were overwhelmed, and bodies were being left on the streets.[S85] On April 7, the Interior Minister of Ecuador announced that face masks were mandatory in public[S86]—at least 48 days (and possibly 53 days) after the local onset of the outbreak. By May 9, the reported mortality was 97.3 per million.

The first case of COVID-19 in Brazil was reported on February 26.[S37] In Brazil, the prevalence of mask wear in public was 25% by March 14, 28% by March 21, 39% by April 4, and 56% by April 12[52]—50 days after the virus is estimated to have arrived in the country. By May 9, the per-capita mortality was 50.1 per million.

Graphical Analysis of Mask Effect.

Before the formal statistical analysis, we graphically illustrate the effect of mask wear (Figures 1, 2). The first figure demonstrates the effect of early mask usage (Figure 1). In the countries not using masks by April 16, or not using them until 60 days after the start of the outbreak, the per-capita mortality by May 9 rises dramatically if the infection has persisted in the country over 60 days (Figure 1, red line). On the other hand, countries in which a mask was used from 16 to 30 days after infection onset had per-capita mortality several orders of magnitude less by May 9 (Figure 1, orange line). When countries recommended masks within 15 days of the onset of the outbreak, the mortality was so low that the curve is difficult to distinguish from the x-axis (Figure 1, blue line).

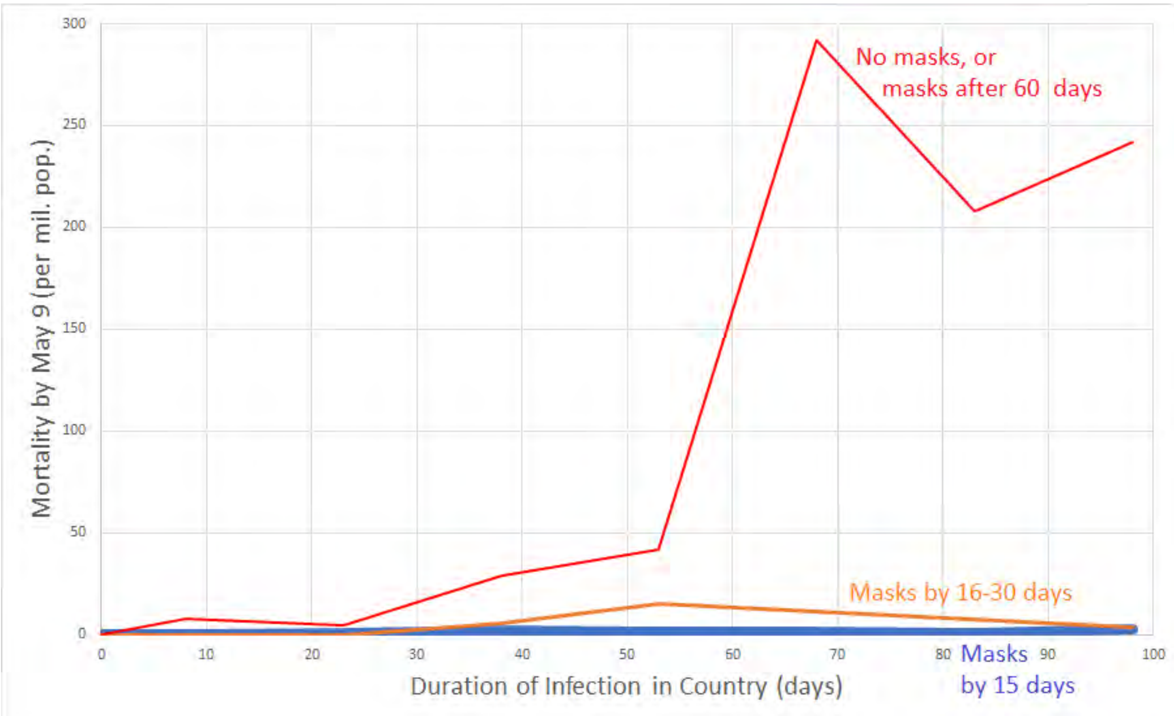

Figure 1. Per-capita mortality by May 9 versus duration of infection according to whether early masking was adopted. Data grouped by whether country did not recommend masks by April 16, 2020 or recommended them more than 60 days after outbreak onset (red line); recommended masks 16 to 30 days after onset of the country's outbreak (orange line); or recommended masks (or traditionally used masks) within 15 days of the outbreak onset (blue line close to the x-axis). Country mortality was averaged for the following country groups of infection duration: 0-15 days, 16-30 days, 31-45 days, 46-60 days, 61-75 days, 76-90 days, 91-105 days. For instance, per-capita mortality for all non-mask or late-masking countries with infection duration between 61 and 75 days was averaged, and graphed at the x-value 68 days. Data for graph derived from 200 countries.

For instance, for the early mask-wearing countries in which the infection had arrived by January (Thailand, Japan, South Korea, Taiwan, Macau, Hong Kong, Vietnam, Cambodia, Malaysia, the Philippines), the virus was present in the country by 80 or more days by April 16 (Table 2). If masks had no effect, we might have expected these countries to have a mortality well over 200 deaths per million (Figure 1). Instead, the mortality for these 10 regions was 2.1 per million (SD 2.5, Table 2)—approximately a 100-fold reduction.

In order to provide some graphical idea of the scatter of the data when exponential growth is assumed, we graphed per-capita mortality by May 9 on a logarithmic scale as a function of the duration of the country's outbreak not using masks in all 200 countries (Figure 2). This simple model explained 28.4% of the variation in per-capita mortality.

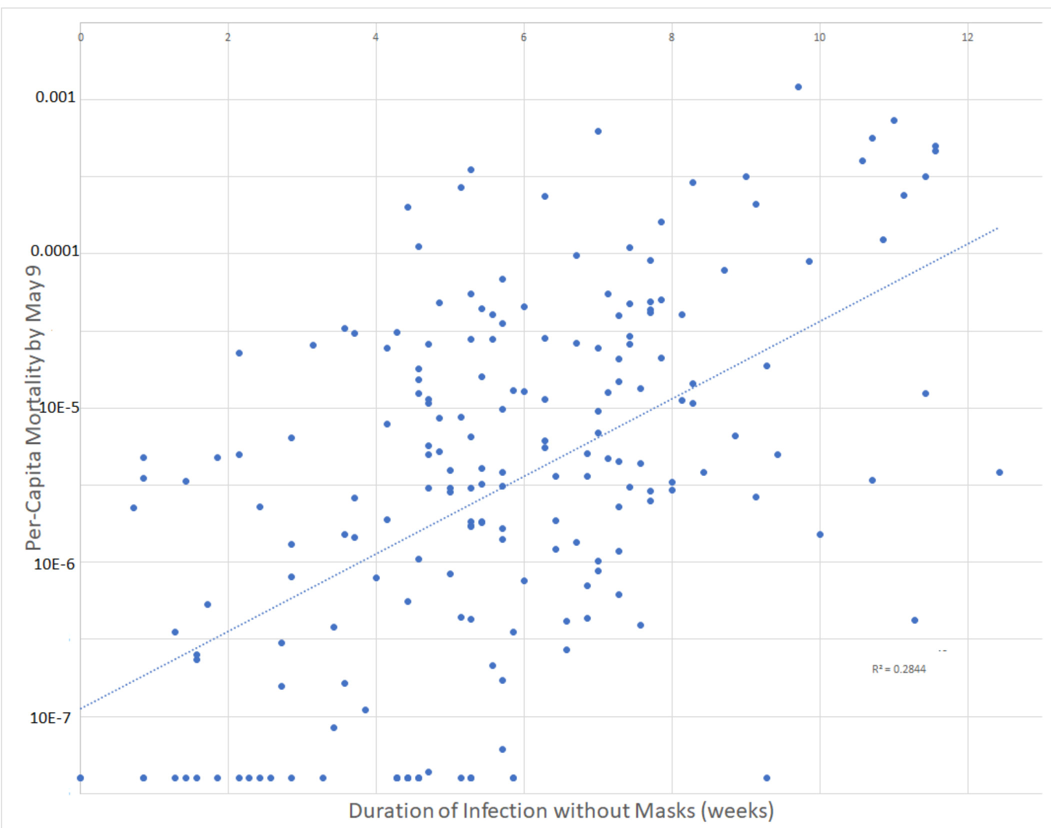

Figure 2. Scatter-plot of per-capita mortality by May 9, 2020 as a function of the period of the country's outbreak without mask recommendations or norms. The dotted line represents the best fit using least-squares linear regression. Data for graph derived from 200 countries. Start of outbreak defined as 5 days before first case reported, or 23 days before the first death (whichever was earlier).

Initial multivariable analyses.

An initial multivariable analysis was conducted including all 200 countries. By multivariable linear regression, significant predictors of the logarithm of each country's per-capita coronavirus mortality included: duration of infection in the country, duration of wearing masks ($p<0.001$), percentage of the population over age 60, and urbanization (all $p\leq0.009$, Appendix Table A2). The association of mortality with the timing of international travel restrictions was of borderline statistical significance ($p=0.051$). The model explained 48.3% of the variation in per-capita mortality (Table A2).

We also prepared a multivariable model to predict the logarithm of per-capita coronavirus mortality in the 196 countries with obesity data. In this model, lockdown, obesity, temperature, and urbanization were retained due to their plausibility as important factors (Table 3). By multivariable linear regression, significant predictors of the logarithm of each country's per-capita coronavirus mortality included: duration of infection in the country, duration of wearing masks, and percentage of the population over age 60 (all $p<0.001$, Table 3). The associations of obesity and or urbanization with increased mortality approached statistical significance ($p=0.10$, Table 3). When controlling for the duration of infection in the country, there appeared to be a negative association between mortality and time in lockdown ($p=0.85$) and time with international travel restrictions ($p=0.07$), though neither association reached statistical significance (Table 3). The model explained 51.0% of the variation in per-capita mortality.

Table 3. Predictors of (log) Country-wide Per-capita Coronavirus Mortality by May 9 by Multivariable Linear Regression in 196 Countries.

	$10^{coefficient}$	Coefficient (SE)	95% CI	P
Duration in country (wks)	1.6210	0.210 (0.036)	0.139 to 0.281	<0.001
Time wearing masks (wks)	0.7145	-0.146 (0.030)	-0.206 to -0.086	<0.001
Time in internal lockdown (wks)	0.9780	-0.0097 (0.050)	-0.108 to 0.089	0.85
Time since start of international travel restrictions (wks)	0.8645	-0.0632 (0.035)	-0.132 to 0.006	0.07
Population, age ≥ 60 (%)	1.1181	0.0485 (0.010)	0.028 to 0.069	<0.001
Urbanization (%)	1.0136	0.00588 (0.004)	-0.001 to 0.013	0.10
Obesity prevalence (%)	1.0337	0.0144 (0.009)	-0.003 to 0.032	0.10
Temperature, ambient (C)	0.9904	-0.0042 (0.009)	-0.022 to 0.013	0.63
Constant	--	-7.661 (0.395)	-8.44 to -6.88	<0.001

Duration of infection in country from estimated date of first infection until 23 days before May 9, 2020 (i.e. April 16). Mask and lockdown durations run from the stated event (mask recommendation or lockdown) or estimated date of first infection in the country (whichever was later) until 23 days before May 9, 2020 (i.e. April 16). Model r^2=0.510.

In countries not recommending masks, the per-capita mortality tended to increase each week by a factor of 1.621, or 62.1%. In contrast, in countries recommending masks, the per-capita mortality tended to increase each week by a factor of 1.6210 * 0.7145 = 1.158, or just 15.8%. With international travel restrictions in place (without masks), the per-capita mortality increased each week by (1.6210)(0.8645) = 1.401, or 40.1%. Under lockdown (without masks), the per-capita mortality increased each week by (1.6210)(0.9780) = 1.585, or 58.5%, i.e. slightly less than the baseline condition (Table 3).

A country with 10% more of its population living in an urban environment than another country tended to suffer a mortality 14.5% higher ($10^{0.0588}$ = 1.145, Table 3). A country in which the percentage of the population age 60 or over is 10% higher than in another country tended to suffer mortality 206% higher ($10^{0.485}$ = 3.06, Table 3). A country with a prevalence of obesity 10% higher tended to suffer mortality 39% higher ($10^{0.144}$ = 1.39, Table 3).

Numbers of Viral Tests.

Among the 183 countries with viral (PCR) testing data by May 9, per-capita testing performed at all 3 time points was positively associated with per-capita mortality in univariate analysis (all p<0.001, Table 1). By May 9, 2020, low-mortality countries had performed 1 test for every 575 members of the population, while high-mortality countries had performed 1 test for every 81 members of the population (p<0.001, Table 1).

To the multivariable model (Table 3), we added testing by May 9, using data from 179 countries with both testing and obesity data. Duration of infection in the country, the duration that masks were recommended, and age at least 60 years continued to be significant predictors of per-capita mortality (all p≤0.001, Appendix Table A3). The model explained 52.5% of the variation in per-capita mortality. Each week the infection persisted in a country without masks was associated with a 62.7% increase in per-capita mortality (Table A3). In contrast, in countries where masks were recommended, the per-capita mortality tended to increase each week by 19.1% (because (1.6271)(0.7319) = 1.191, Table A3). In this model, the prevalence of obesity was associated with increased country-wide per-capita mortality, though the association was not significant (p=0.09). If the prevalence of obesity increased by 10% (e.g. from 10% to 20% of a population), the per-capita mortality tended to increase by 47% (Table A3)

In this model, a 10-fold increase (i.e. one logarithm) in per-capita testing tended to be associated with a 26.0% increase in reported per-capita mortality, though the trend was not close to reaching statistical significance (p=0.38, Appendix Table A3).

If early testing lowers mortality, one might expect negative regression coefficients. Testing on both April 16 and May 9 were added to the multivariable model of Table 3, using data from the 158 countries with both obesity and testing data by these dates. Per-capita testing (log) by April 16 was not negatively associated with per-capita mortality (log) by May 9 (coefficient 0.211, 95% CI -0.305 to 0.868, p=0.34).

Likewise, testing on both April 4 (the earliest archived data) and May 9 were added to the multivariable model of Table 3, using data from the 131 countries with both obesity and testing data by these dates. Per-capita testing (log) by April 4 was not significantly associated with per-capita mortality (log) by May 9 (coefficient -0.0535, 95% CI -0.380 to 0.273, p=0.75). Given the coefficient, a 10-fold (one log) increase in early testing would be associated with a (non-significant) decrease in per-capita mortality of 11.6%.

Only 5 countries had performed over 1 test for every 10 people in the country by May 9, 2020 (in order of most testing to least): the Faeroe Islands, Iceland, the Falkland Islands, the UAE, and Bahrain. The Faeroe and Falkland Islands reported no coronavirus-related deaths. The highest per-capita mortality among this group was 29.0 per million population (or 1 in 34,480 people), seen in Iceland.

Containment and Testing Policies.

For 169 countries, containment, testing, and health policies were scored by Oxford University.[9] The following countries with mask policies by April 16 were included in this analysis, but not in the previous multivariable model, for lack of data on numbers of tests performed: China, Macau, Cameroon, Sierra Leone, and Sudan. In univariate analysis, scores for school closing, cancelling public events, international travel controls, and index of containment and health were significantly associated with lower per-capita mortality (all p<0.05, Table 4). Policies regarding workplace closing, restrictions on gatherings, closing public transport, stay at home requirements, internal movement restrictions, public information campaigns, testing, and contact tracing were not significant predictors of mortality (all p>0.05, Table 4). Likewise, overall indices of stringency and government response were not associated with mortality (all p>0.05, Table 4).

Table 4. Government policies in 169 countries with low and high per-capita coronavirus mortality by May 9, 2020.

	Mean (SD)		p value
	Low Mortality	High Mortalilty	
School closing (0-3)	2.08 (0.65)	1.84 (0.49)	0.006
Workplace closing (0-3)	1.21 (0.74)	1.34 (0.47)	0.19
Cancel public events (0-2)	1.39 (0.45)	1.21 (0.34)	0.005
Restrictions on gatherings (0-4)	2.00 (0.84)	1.76 (0.87)	0.07
Close public transport (0-2)	0.64 (0.51)	0.58 (0.45)	0.41
Stay at home requirements (0-3)	0.84 (0.61)	0.89 (0.46)	0.52
Internal movement restrictions (0-2)	0.92 (0.52)	0.85 (0.38)	0.33
International travel controls (0-4)	2.88 (0.72)	2.43 (0.83)	<0.001
Income support (0-2)	0.15 (0.24)	0.55 (0.41)	<0.001
Debt / contract relief (0-2)	0.35 (0.42)	0.58 (0.46)	<0.001
Public information campaigns (0-2)	1.70 (0.36)	1.62 (0.44)	0.19
Testing policy (0-3)	1.12 (0.57)	1.05 (0.48)	0.35
Contact tracing (0-2)	1.08 (0.66)	1.02 (0.60)	0.53
Stringency Index (0-100)	53.4 (14.6)	49.4 (12.9)	0.06
Government response index (0-100)	45.9 (11.7)	44.8 (10.7)	0.53
Containment & health index (0-100)	52.0 (13.1)	48.2 (11.7)	0.047
Economic support index (0-100)	11.9 (13.7)	26.0 (16.6)	<0.001

Government policies were scored by Oxford University.[9] Characterization as low or high mortality was defined by the median for all 200 countries.

A multivariable model in 169 countries found that duration of the infection, duration masks were recommended, prevalence of age at least 60 years, obesity, and international travel restrictions were independently predictive of per-capita mortality (Table 5). The model explained 66.8% of the variation in per-capita mortality. At baseline, each week of the infection in a country without masks was associated with an increase in per-capita mortality of 50.9% (Table 5). In contrast, for each week that masks were worn, the per-capita mortality was associated with a lesser increase of 12.4% each week (given that 1.5085 (0.7449) = 1.124, Table 5).

International travel restrictions were scored by Oxford as: (0) no measures, (1) screening, (2) quarantine arrivals from high-risk regions; and ban on arrivals from some (3) or all (4) regions. The international travel restrictions were scored as 4 in Greenland, 3.8 in Bermuda, 3.6 in Israel, 3.5 in Czechia and New Zealand, 3.1 in Taiwan, and 2.9 in Australia, and at the other extreme, were scored as 1.1 in Sweden, and as 0 in Iran, Luxembourg, and the UK.

International travel restrictions were associated with lower mortality, regardless of whether incorporated in the model as time since onset, or as mean score during the outbreak. We present the model based on the former because of the strength of the association, and for consistency with the models presented previously. The regression analysis suggested that for each week of travel restrictions (without masks), the per-capita mortality increased by 25.1% (given that 1.5085 (0.8291) = 1.251, Table 5).

Table 5. Predictors of (log) Country-wide Per-capita Coronavirus Mortality by May 9 by Multivariable Linear Regression in 169 Countries.

	$10^{coefficient}$	Coefficient (SE)	95% CI	P
Duration in country (wks)	1.5085	0.1785 (0.031)	0.118 to 0.239	<0.001
Time wearing masks (wks)	0.7449	-0.1279 (0.026)	-0.178 to -0.077	<0.001
Time in lockdown (wks)	1.0195	0.0082 (0.044)	-0.076 to 0.093	0.85
Time since start of international travel restrictions (wks)	0.8291	-0.0814 (0.029)	-0.140 to -0.023	0.006
Population, age ≥ 60 (%)	1.1725	0.0691 (0.009)	0.051 to 0.087	<0.001
Urbanization (%)	1.0149	0.0064 (0.003)	-0.0004 to 0.013	0.07
Obesity prevalence (%)	1.0459	0.0195 (0.008)	0.003 to 0.036	0.02
Temperature, ambient (C)	1.0190	0.0082 (0.008)	-0.007 to 0.023	0.29
Testing policy (0-3)	1.0286	0.0122 (0.111)	-0.207 to 0.232	0.91
Contact tracing (0-2)	0.6737	-0.172 (0.092)	-0.353 to 0.010	0.06
Constant	--	-7.885 (0.346)	-8.57 to -7.20	<0.001

Duration of infection in country from estimated date of first infection until 23 days before May 9, 2020 (i.e. April 16). Mask and lockdown durations run from the stated event (mask recommendation or lockdown) or estimated date of first infection in the country (whichever was later) until 23 days before May 9, 2020 (i.e. April 16). Policies on testing, contact tracing, and international travel controls were scored by Oxford University. Model r^2=0.668.

Per-capita mortality was not significantly associated with policies regarding either testing policy (p=0.91), or contact tracing (p=0.06, Table 5). Testing policy was scored as: no policy (0), symptomatic with exposure, travel history, hospitalization, or key occupation (1), all symptomatic (2), or open to anyone (3). Testing policy tended to be positively associated with mortality. Contact tracing was scored as: none (0), some cases (1), or all cases (2), and tended to be inversely related with per-capita mortality (though not significantly). These countervailing associations meant that as compared with a country with no testing or tracing policy, a country which opened testing to the entire public with comprehensive contact tracing might be associated with a reported change in mortality of
$10^{(3*0.0122+2*(-0.172))}$ = 0.493, i.e. a 51.7% reduction in per-capita mortality (though statistical significance was not demonstrated). Thus, testing and tracing may be important factors, but seem unlikely to account for the majority of the 100-fold variation in per-capita mortality between low and high mortality countries early in the course of the pandemic.

Survey-modified Model.

Surveys of mask wearing by the public during the exposure period were available for 41 countries (see above). To determine the influence that actual mask-wear, as opposed to mask policies, might have on the model, we scored countries as mask-wearing if at least 50% of the public wore a mask, and non-mask wearing if less than 50% of the population did so.

Based on surveys, Canada, Finland, France, Germany, and Malawi were not considered mask-wearing countries at any time during the exposure period (ending April 16). In contrast, Italy was scored as mask-wearing beginning March 19,[53] Spain[53] and India[52] beginning March 21, Saudi Arabia beginning April 1,[53] Russia beginning April 4, Singapore beginning April 10,[53] and the United States, Brazil and Mexico beginning April 12.[52,53]

In this survey-modified model in 200 countries, duration of the outbreak, duration of mask wear, proportion of the population age 60 or over, and urbanization were all significant predictors of per-capita mortality (all p<0.01, Appendix Table A4). Time since the start of international travel restrictions tended to be inversely associated with mortality (p=0.051). Each week that the infection persisted in the country without masks was associated with a 59.9% increase in per-capita mortality. On the other hand, when masks were worn, the per-capita mortality only increased by 9.3% weekly, (1.5993)(0.6836) = 1.093, (Appendix Table A5). The model explained 48.3% of the variance in mortality.

Discussion.

These results confirm that in the first 4 months of 2020, there was marked variation between countries in mortality related to COVID-19. Countries in the lower half of mortality experienced an average COVID-19-related per-capita mortality of 0.99 deaths per million population, in contrast with an average of 93.3 deaths per million in the remaining countries. Depending on the model and dataset evaluated, statistically significant independent predictors of per-capita mortality included urbanization, fraction of the population age 60 years or over, prevalence of obesity, duration of the outbreak in the country, international travel restrictions, and the period of the outbreak subject to cultural norms or government policies favoring mask-wearing by the public.

These results support the universal wearing of masks by the public to suppress the spread of the coronavirus.[1] Given the low levels of coronavirus mortality seen in the Asian countries which adopted widespread public mask usage early in the outbreak, it seems highly unlikely that masks are harmful.

On April 30, 2020, we originally published the finding that the logarithm of per-capita coronavirus mortality is linearly and positively associated with the duration of the outbreak without mask norms or mandates .[46] This key finding was recently confirmed by Goldman Sachs chief economist Jan Hatzius, who cited our work.[107] The regression analysis performed by Goldman Sachs confirms that, for prediction of both infection prevalence and mortality, the significance of the duration of mask mandates or norms in the model persists after controlling for age of the population, obesity, population density, and testing policy.[107]

One major limitation is that evidence concerning the actual prevalence of mask-wearing by the public is unavailable for most countries. Our survey of the literature is one of the more complete evaluations of the question to date. Available scholarship and surveys do corroborate reports in the news media that mask wear was common in public in many Asian countries, including Japan, the Philippines, Hong Kong, Vietnam, Malaysia, Taiwan, Thailand, China, Indonesia, India, Myanmar and Bangladesh (Table 2). Internet search data are consistent with interest in masks developing much earlier in the course of the pandemic in Asia than elsewhere.[108,109] Mask wear was widespread in some low-mortality countries even before, or in the absence of, a formal government recommendation.

In addition, it is likely that the policies favoring mask-wearing in parts of the Middle East, Africa, Latin America and the Caribbean were markers of a general cultural acceptance of masks that helped to limit spread of the virus. Had there been adequate survey data to fully reflect the early wearing of masks in these regions, it is possible that the association of masks with lower mortality would be even stronger.

Conversely, in Western countries which had no tradition of mask-wearing, and which only recommended (rather than mandated) mask-wearing by the public, such as the United States, the practice has been steadily increasing, but change has not been immediate.

Much of the randomized controlled data on the effect of mask-wearing on the spread of respiratory viruses relates to influenza. One recent meta-analysis of 10 trials in families, students, or religious pilgrims found that the relative risk for influenza with the use of face masks was 0.78, a 22% reduction, though the findings were not statistically significant.[110] Combining all the trials, there were 29 cases in groups assigned to wear masks, compared with 51 cases in control groups.[110] The direct applicability of these results to mask-wearing at the population level is uncertain. For instance, there was some heterogeneity in methods of the component trials, with one trial assigning mask wearing to the person with a respiratory illness, another to his close contacts, and the remainder to both the ill and their contacts.[110] Mask-wearing was inconsistent. The groups living together could not wear a mask when bathing, sleeping, eating, or brushing teeth.[111-113] In one of the studies reviewed, parents wore a mask during the day, but not at night when sleeping next to their sick child.[113] In a different trial, students were asked to wear a mask in their residence hall for at least 6 hours daily (rather than all the time).[111] The bottom line is that it is nearly impossible for people to constantly maintain mask wear around the people with whom they live. In contrast, wearing a mask when on public transit or shopping is quite feasible. In addition, as an infection propagates through multiple generations in the population, the benefits multiply exponentially. Even if one accepts that masks would only reduce transmissions by 22%, then after 10 cycles of the infection, mask-wearing would reduce the level of infection in the population by 91.7%, as compared with a non-mask wearing population, at least during the period of exponential growth (because $0.78^{10} = 0.083$). It is highly unlikely that entire countries or populations will ever be randomized to either wear, or not wear, masks. Public policies can only be formulated based on the best evidence available.

Some countries which used masks were better able to maintain or resume normal business and educational activities. For instance, in Taiwan, schools reopened on February 21, 2020, with parents directed to purchase 4 to 5 masks per week for each child.[S265]

Limits on international travel were significantly associated with lower per-capita mortality from coronavirus. On the other hand, nationwide policies to ban large gatherings and to close schools or businesses, tended to be associated with lower mortality, though not in a statistically significant fashion. However, businesses, schools, and individuals made decisions to limit contact, independent of any government policies. The adoption of numerous public health policies at the same time can make it difficult to tease out the relative importance of each.

Colder average monthly temperature was associated with higher levels of COVID-19 mortality in univariate analysis, but not when accounting for other independent variables. One reason that outdoor temperature might have limited association with the spread of the virus is that most viral transmission occurs indoors.[114] We acknowledge that using the average temperature in the country's largest city during the outbreak does not model the outbreak as precisely as modelling mortality and temperature separately in each of the thousands of cities around the world. However, to a first approximation, our method did serve to control for whether the country's climate was tropical, temperate, or polar, and whether the outbreak began in late Winter (Northern hemisphere) or late Summer (Southern hemisphere). Environmental factors which could influence either human behavior or the stability and spread of virus particles are worthy of further study.

Presumably, high levels of testing might identify essentially all coronavirus-related deaths, and still higher levels of testing, combined with contact tracing, might lower mortality. Statistical support for the benefit of mass testing could not be demonstrated. It seems likely that countries which test at a low level are missing many cases. We identified just 5 countries (Iceland, the Faeroe Islands, the UAE, the Falkland Islands, and Bahrain) which had tested over one tenth of their population by May 9. All 5 countries had a mortality of 29 per million (1 in 34,480 people) or less. The degree to which these results would apply to larger, less isolated, or less wealthy countries is unknown. Statistical support for benefit of high levels of testing might be demonstrated if additional and more diverse countries are able to test at this level. The benefits of contact tracing policies with respect to mortality were of marginal statistical significance (p=0.06).

One limitation of our study is that the ultimate source of mortality data is often from governments which may not have the resources to provide a full accounting of their public health crises, or an interest in doing so. It should be noted that the benefit of wearing masks persisted in a model which excluded data from China (because no testing data were available, Appendix Table A3). We also acknowledge that country-wide analyses are subject to the ecologic fallacy.

The source for mortality and testing data we selected is publicly available,[7] has been repeatedly archived,[11] contains links to the source government reports for each country, and agrees with other coronavirus aggregator sites.[115] In the interest of transparency, we presented the per-capita mortality data in Appendix Table A1. One might question whether any of these data sites or governments provide a complete and accurate picture of coronavirus mortality. But we must remember that this information does not exist in a vacuum. Independent sources confirm when mortality has been high. Social media alerted the world to the outbreaks in Wuhan, Iran, Italy, and New York. News reports have used aerial photography to confirm the digging of graves in Iran, New York, and Brazil. Long lines were seen to retrieve remains at crematoria in Wuhan. Mortuary facilities were inadequate to meet the demand in New York, and Guayaquil.[S85] Conversely, signs of health system overload have been noted to be absent in the countries reporting low mortality. The health systems in Hong Kong, Taiwan, Japan, and South Korea are believed to be transparent. Reporters in Vietnam have even called hospitals and funeral homes to confirm the absence of unusual levels of activity.[S297] Therefore, while no data source is perfect, we believe that the data used in the paper are consistent with observations from nongovernmental sources, and are comparable in reliability to those in other scholarly works.

It is not the case that countries which reported no deaths due to coronavirus simply were not exposed to the virus. All 200 countries analyzed did report COVID-19 cases. Several countries which traditionally use masks and sustained low mortality (or none) are close to and have strong travel links to China. Some of these countries reported cases early in the global pandemic (Table 2). Community transmission has been described in Vietnam.[116]

The pandemic is a matter of universal concern, but ophthalmologists have specific reasons to understand and prevent infection with SARS-CoV-2. The virus can cause a conjunctivitis, and has been identified in tears.[117,118] It is possible that transmission can occur by conjunctival exposure to droplets.[117] Ophthalmology was among the specialties whose residents were at higher risk of coronavirus infection.[119] COVID-19 claimed the lives of 3 ophthalmologists from Wuhan Central Hospital, including 33-year-old Li Wenliang, who was admonished for sharing news of the novel pneumonia online.[117,S61] As of April 15, 2020, at least 8 ophthalmologists had died from COVID.[120]

In summary, older age of the population, urbanization, obesity, and longer duration of the outbreak in a country were independently associated with higher country-wide per-capita coronavirus mortality. International travel restrictions were associated with lower per-capita mortality. However, other containment measures, testing and tracing polices, and the amount of viral testing were not statistically significant predictors of country-wide coronavirus mortality, after controlling for other variables. In contrast, societal norms and government policies supporting mask-wearing by the public were independently associated with lower per-capita mortality from COVID-19. The use of masks in public is an important and readily modifiable public health measure.

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Appendix. Supplemental Tables.

Table A1. Per-capita COVID-19 Mortality by May 9 and Date of Mask Recommendation or Widespread Use Based on Cultural Norms.

Country.	COVID-19 Mortality (per M. pop.) by May 9.	Date Masks Recommended or Widely Used by Cultural Norms.
Afghanistan	3.0	
Albania	10.8	
Algeria	11.3	5/18/2020
Andorra	621.2	4/17/2020
Angola	0.1	4/23/2020
Antigua & Barbuda	30.6	4/5/2020
Argentina	6.6	4/18/2020
Armenia	14.8	5/14/2020
Aruba	28.1	
Australia	3.8	
Austria	68.3	3/30/2020
Azerbaijan	3.1	5/1/2020
Bahamas	28.0	4/19/2020
Bahrain	4.7	4/9/2020
Bangladesh	1.3	3/19/2020
Barbados	24.4	4/11/2020
Belarus	13.3	
Belgium	740.4	4/24/2020
Belize	5.0	5/1/2020
Benin	0.2	4/6/2020
Bermuda	112.4	
Bhutan	0.0	3/11/2020
Bolivia	9.8	
Bosnia & Herzegov.	31.1	3/29/2020
Botswana	0.4	5/1/2020
Brazil	50.1	
British Virgin Is.	33.1	4/28/2020
Brunei	2.3	3/22/2020
Bulgaria	13.0	3/30/2020
Burkina Faso	2.3	4/20/2020
Burundi	0.1	
Cabo Verde	3.6	5/5/2020
Cambodia	0.0	1/28/2020
Cameroon	4.1	4/9/2020
Canada	124.3	4/6/2020
Carib. Netherlands	0.0	
Cayman Is.	15.2	3/30/2020
Central Afric. Rep.	0.0	
Chad	1.9	4/13/2020
Channel Is.	235.8	
Chile	15.9	4/6/2020
China	3.2	1/20/2020
Colombia	8.7	4/4/2020

Congo (Brazzaville)	1.8	4/30/2020
Costa Rica	1.2	
Croatia	21.2	4/24/2020
Cuba	6.5	4/2/2020
Curacao	6.1	
Cyprus	12.4	4/3/2020
Czechia	25.8	3/19/2020
Dem. Rep. Congo	0.4	
Denmark	90.8	
Djibouti	3.0	5/10/2020
Dominica	0.0	4/9/2020
Dominican Republic	35.5	4/6/2020
Ecuador	97.3	4/7/2020
Egypt	5.0	5/31/2020
El Salvador	2.6	4/4/2020
Equatorial Guinea	2.9	4/14/2020
Eritrea	0.0	
Estonia	45.2	4/5/2020
Eswatini	1.7	
Ethiopia	0.0	4/11/2020
Faeroe Islands	0.0	
Falkland Islands	0.0	
Fiji	0.0	
Finland	47.8	4/14/2020
France	403.1	4/3/2020
French Polynesia	0.0	
Gabon	3.6	4/15/2020
Gambia	0.4	
Georgia	2.5	4/17/2020
Germany	90.1	4/1/2020
Ghana	0.7	4/19/2020
Gibraltar	0.0	
Greece	14.5	4/27/2020
Greenland	0.0	
Grenada	0.0	4/3/2020
Guatemala	1.3	4/9/2020
Guinea	0.8	4/13/2020
Guinea-Bissau	1.5	5/11/2020
Guyana	12.7	4/9/2020
Haiti	1.1	5/4/2020
Honduras	10.8	4/6/2020
Hong Kong	0.5	1/24/2020
Hungary	41.9	4/29/2020
Iceland	29.3	
India	1.5	4/4/2020
Indonesia	3.5	2/24/2020
Iran	78.4	3/29/2020
Iraq	2.7	4/19/2020
Ireland	292.8	5/15/2020
Isle of Man	270.5	
Israel	28.5	4/1/2020
Italy	502.7	4/28/2020
Ivory Coast	0.8	4/4/2020

Jamaica	3.0	4/8/2020
Japan	4.8	1/16/2020
Jordan	0.9	4/27/2020
Kazakhstan	1.7	5/26/2020
Kenya	0.6	4/4/2020
Kuwait	11.5	3/23/2020
Kyrgyzstan	1.8	5/10/2020
Laos	0.0	3/6/2020
Latvia	9.5	4/27/2020
Lebanon	3.8	4/25/2020
Liberia	4.0	4/24/2020
Libya	0.4	4/16/2020
Liechtenstein	26.2	5/15/2020
Lithuania	18.0	3/26/2020
Luxembourg	161.3	4/15/2020
Macao	0.0	1/23/2020
Madagascar	0.0	4/20/2020
Malawi	0.2	4/4/2020
Malaysia	3.3	1/30/2020
Maldives	5.5	5/19/2020
Mali	1.8	5/10/2020
Malta	11.3	5/1/2020
Mauritania	0.2	5/6/2020
Mauritius	7.9	3/31/2020
Mayotte	40.3	5/11/2020
Mexico	26.0	5/5/2020
Moldova	39.9	5/7/2020
Mongolia	0.0	1/31/2020
Montenegro	12.7	4/30/2020
Montserrat	200.3	4/29/2020
Morocco	5.0	4/6/2020
Mozambique	0.0	4/4/2020
Myanmar	0.1	4/5/2020
Namibia	0.0	5/2/2020
Nepal	0.0	3/25/2020
Netherlands	316.4	5/6/2020
New Caledonia	0.0	4/30/2020
New Zealand	4.4	
Nicaragua	0.8	
Niger	1.9	5/12/2020
Nigeria	0.6	4/14/2020
North Macedonia	43.7	4/23/2020
Norway	40.4	
Oman	3.3	5/18/2020
Pakistan	2.9	5/31/2020
Palestine	0.4	5/5/2020
Panama	54.9	4/7/2020
Papua New Guinea	0.0	4/24/2020
Paraguay	1.4	4/7/2020
Peru	55.0	4/3/2020
Philippines	6.4	1/30/2020
Poland	20.7	4/10/2020
Portugal	110.4	4/27/2020

Qatar	4.5	4/22/2020
Réunion	0.0	5/7/2020
Romania	48.8	4/22/2020
Russia	12.5	5/11/2020
Rwanda	0.0	4/18/2020
Saint Kitts & Nevis	0.0	4/2/2020
Saint Lucia	0.0	4/7/2020
San Marino	1208.3	4/17/2020
São Tomé & Príncipe	22.8	4/22/2020
Saudi Arabia	6.9	4/28/2020
Senegal	1.0	4/17/2020
Serbia	24.4	4/29/2020
Seychelles	0.0	6/9/2020
Sierra Leone	2.3	4/1/2020
Singapore	3.4	4/3/2020
Sint Maarten	349.8	4/18/2020
Slovakia	4.8	3/15/2020
Slovenia	48.6	3/29/2020
Somalia	3.0	
South Africa	3.1	4/10/2020
South Korea	5.0	1/30/2020
South Sudan	0.0	4/29/2020
Spain	566.3	4/11/2020
Sri Lanka	0.4	4/11/2020
St. Vincent & Gren.	0.0	4/26/2020
Sudan	1.5	3/16/2020
Suriname	1.7	5/31/2020
Sweden	318.8	
Switzerland	211.4	6/15/2020
Syria	0.2	
Taiwan	0.3	1/27/2020
Tanzania	0.4	
Thailand	0.8	1/28/2020
Timor-Leste	0.0	3/28/2020
Togo	1.2	4/19/2020
Trinidad & Tobago	5.7	4/5/2020
Tunisia	3.8	4/7/2020
Turkey	44.3	4/3/2020
Turks and Caicos	25.8	4/30/2020
Uganda	0.0	5/1/2020
Ukraine	8.6	3/30/2020
United Arab Emir.	18.7	3/27/2020
United Kingdom	465.3	5/11/2020
United States	241.8	4/3/2020
Uruguay	5.2	4/10/2020
Uzbekistan	0.3	3/25/2020
Venezuela	0.4	3/13/2020
Vietnam	0.0	1/27/2020
Yemen	0.2	
Zambia	0.4	4/4/2020
Zimbabwe	0.3	5/1/2020

Table A2. Predictors of (log) Country-wide Per-capita Coronavirus Mortality by May 9 by Multivariable Linear Regression in 200 Countries.

	$10^{coefficient}$	Coefficient (SE)	95% CI	P
Duration in country (weeks)	1.5993	0.2039 (0.037)	0.131 to 0.277	<0.001
Time wearing masks (weeks)	0.6836	-0.1652 (0.030)	-0.224 to -0.106	<0.001
Time since international travel restrictions (weeks)	0.8529	-0.0691 (0.035)	-0.139 to 0.0004	0.051
Time in internal lockdown (weeks)	1.0210	0.0090 (0.051)	-0.092 to 0.110	0.86
Population, age≥60 (%)	1.1367	0.0556 (0.010)	0.035 to 0.076	<0.001
Urbanization (%)	1.0185	0.00796 (0.003)	0.002 to 0.014	0.009
Temperature (C)	0.9988	-0.00052 (0.009)	-0.018 to 0.017	0.95
Constant	--	-7.66 (0.393)	-8.43 to -6.88	<0.001

Duration of infection in country from estimated date of first infection until 23 days before May 9, 2020 (i.e. April 16). Mask and lockdown durations run from the stated event (mask recommendation or lockdown) or estimated date of first infection in the country (whichever was later) until 23 days before May 9, 2020 (i.e. April 16). Model r^2=0.483.

Table A3. Predictors of (log) Country-wide Per-capita Coronavirus Mortality by May 9 by Multivariable Linear Regression in 179 Countries.

	$10^{coefficient}$	Coefficient (SE)	95% CI	P
Duration in country (weeks)	1.6271	0.211 (0.038)	0.136 to 0.287	<0.001
Time wearing masks (weeks)	0.7319	-0.136 (0.032)	-0.199 to -0.072	<0.001
Time in lockdown (weeks)	0.9877	-0.0054 (0.054)	-0.113 to 0.102	0.92
International travel controls (time since start, weeks)	0.8686	-0.0612 (0.038)	-0.135 to 0.013	0.11
Population, % age 60 or over	1.0909	0.0378 (0.012)	0.015 to 0.061	0.001
Urbanization (%)	1.0132	0.00568 (0.004)	-0.002 to 0.013	0.14
Obesity prevalence (%)	1.0395	0.0168 (0.010)	-0.003 to 0.036	0.09
Temperature (C)	0.9824	-0.0077 (0.009)	-0.026 to 0.010	0.40
Testing (log per cap., by May 9)	1.2604	0.101 (0.115)	-0.127 to 0.328	0.38
Constant	--	-7.309 (0.621)	-8.54 to -6.08	<0.001

Based on 179 countries with both obesity and testing data by May 9. Duration of infection in country from estimated date of first infection until 23 days before May 9, 2020 (i.e. April 16). Mask and lockdown durations run from the stated event (mask recommendation or lockdown) or estimated date of first infection in the country (whichever was later) until 23 days before May 9, 2020 (i.e. April 16). Model r^2=0.525.

Table A4. Predictors of (log) Country-wide Per-capita Coronavirus Mortality by May 9 by Multivariable Linear Regression in 200 Countries, with Mask Wear Determined by Recommendations and Surveys (When Available).

	$10^{coefficient}$	Coefficient (SE)	95% CI	P
Duration in country (weeks)	1.5993	0.204 (0.037)	0.131 to 0.277	<0.001
Time wearing masks (weeks)	0.6836	-0.165 (0.030)	-0.224 to -0.106	<0.001
Time in lockdown (weeks)	0.9021	0.0090 (0.051)	-0.092 to 0.110	0.86
Time since start of international travel controls (weeks)	0.8529	-0.0691 (0.035)	-0.139 to 0.0004	0.051
Population, age≥60 (%)	1.1367	0.0556 (0.010)	0.035 to 0.076	<0.001
Urbanization (%)	1.0185	0.00796 (0.003)	0.002 to 0.014	0.009
Temperature	0.9988	-0.00052 (0.009)	-0.018 to 0.017	0.95
Constant	--	-7.658 (0.393)	-8.434 to -6.882	<0.001

` Duration of infection in country from estimated date of first infection until 23 days before May 9, 2020 (i.e. April 16). Mask and lockdown durations run from the stated event (mask recommendation or lockdown) or estimated date of first infection in the country (whichever was later) until 23 days before May 9, 2020 (i.e. April 16). Model r^2=0.483.

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