Article title: Preventative and Proactive Measures to Mitigate the Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)
Authors: James Young[1], Emily He[2], DaLoria Boone[3], Julia Luehr[4], Kazi Tasnim[5], Meghan Turner[6], Mythri Ambatipudi[7], Paola Carrillo Gonzalez[8], David Mooney[9], Esther Koh[10]
Affiliations: John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA[1]
Orcid ids: 0000-0002-1483-0764[1], 0000-0002-1551-1503[2], 0000-0002-7460-7492[7], 0000-0001-6299-1194[9], 0000-0001-8542-888X[10]
Contact e-mail: emily_he@college.harvard.edu

DOI: 10.14293/S2199-1006.1.SOR-.PPAAHGK.v1
Preprint first posted online: 23 June 2021
Keywords: COVID-19, SARS-CoV-2, masks, contact tracing, physical distancing, Corona virus

Preventative and Proactive Measures to Mitigate the Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)

Authors

James R. Young[a,b†], Emily M. He[a,b,†], DaLoria Boone[a,b], Julia B. W. Luehr[a,b], Kazi Tasnim[a,b], Meghan K. Turner[a,b], Mythri Ambatipudi[a,b], Paola Carrillo Gonzalez[a,b], David J. Mooney[b,c,‡], Esther Koh[a,b,‡,*]

[a]Harvard College, Harvard University, Cambridge, MA, USA

[b]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA

[c]Wyss Institute for Biologically Inspired Engineering, Harvard University, Cambridge, MA, USA

[†]These authors contributed equally to this work.

[‡]These authors contributed equally to this work.

*Corresponding author. Email: ekoh@college.harvard.edu, Phone: +1 (951) 776-6208, Address: 95 Dunster St., 335 Kirkland Mail Center, Cambridge, Massachusetts, USA.

Abstract

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission can be mitigated through a combination of preventive and proactive measures. In this review, we first highlight modes of SARS-CoV-2 transmission, quantitatively assess individual mitigation measures, and conclude with a qualitative comparison. We detail how the efficacy of specific face masks must be balanced with their availability, while for comparison, social distancing and good hygiene practices may not be as directly effective as respirators but are widely accessible methods not subject to limited supplies. Controlling environmental setting, testing, and contact tracing are highly effective mitigation practices, but typically require collective action versus the individual activity of the former strategies. Our qualitative comparative assessment of preventative mitigation factors (i.e., face mask usage, social distancing, hygiene, and choice of environment setting) and proactive mitigation measures (i.e., testing, and contact tracing) serves to inform communities on the effectiveness and feasibility of these strategies.

Keywords

COVID-19, SARS-CoV-2, masks, contact tracing, physical distancing, hygiene

1. Introduction

The COVID-19 pandemic is a global health threat [1]. National health systems have been strained by COVID-19's rapid spread, leading to shortages in intensive care unit beds, ventilators, and personal protective equipment (PPE) [2-4].

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the etiologic agent of COVID-19, has high communicability [5], underlining the critical need for effective mitigation methods. Different combinations of mitigation measures have had varying levels of success. In the initial outbreak in Wuhan, China, mitigation measures such as lockdown, quarantine of infected populations, and social distancing helped significantly diminish reported cases [6]. In New Zealand, stringent border control with quarantine of incoming travelers, widespread testing resulting in rapid case detection and consequent isolation, contact tracing, and intensive hygiene promotion eliminated COVID-19 transmission within the country [7,8]. On university campuses, mask mandates, rigorous testing and tracing systems, social distancing measures, and de-densification kept positivity rates under 1% [9,10]. In conjunction, these examples indicate that combinations of social distancing, good hygiene practices, mask use, as well as testing and contact tracing systems are effective in limiting transmission.

Vaccines that allow for safe and effective immunization are another valuable mitigation method [11-13]. However, widespread vaccine distribution, and thus widespread viral immunity, may take months. Since vaccinated individuals may still spread the virus to others, they are still recommended to follow community mitigation guidelines [14]. The emergence of potentially more contagious variants emphasizes the need for stricter mitigation measures [15].

In this review, we highlight and compare general mitigation strategies shown to be effective in reducing SARS-CoV-2 transmission. An overview of the modes of SARS-CoV-2 transmission, including its forms and dynamics, is first provided. Quantitative analysis of preventative mitigation factors (i.e., face mask usage, social distancing, hygiene and choice of environmental setting) and proactive mitigation measures (i.e., testing and contact tracing) is then described. We conclude with a qualitative comparison of the effectiveness of preventative and proactive measures, and potential directions for further research.

2. Modes of SARS-CoV-2 Transmission

2.1 Forms of Airborne Transmission

Airborne transmission is the primary means of SARS-CoV-2 particle movement [16]. Current evidence shows that airborne transmission occurs primarily through two forms —droplets and aerosols—but does not exclude fomites (contaminated surfaces) as a potential mode of transmission of SARS-CoV-2 [16].

2.1.1 Droplets

Aqueous drops expelled from the respiratory tract that are >5 μm in diameter are termed droplets [16]. SARS-CoV-2 virions are approximately 0.1 μm in diameter and are encapsulated in droplets expelled from the respiratory tract of infected individuals [17]. Transmission via droplets occurs when an individual 1) directly ingests droplets expelled from an infected person or 2) touches droplets on a surface followed by contact transfer to the respiratory tract [18]. The size threshold below which droplets evaporate prior to reaching the ground (i.e., critical size) and expiration velocity determine how far droplets can travel from an individual, thus defining the distance at which viral transmission via droplets is possible [19]. In conjunction, critical size and expiration velocity studies approximate that infectious droplets can traverse <1m when breathing, ~2m when coughing, and >6m when sneezing [19].

2.1.2 Aerosols

Smaller particles (<5 µm in diameter) that evaporate before they fall to rest on a surface form minute droplets, formally known as aerosols, which contain active viral particles [20]. Aerosols can remain suspended for hours, or even days, and therefore can travel farther from their origin [16]. Asymptomatic and presymptomatic infected individuals are believed to mainly spread SARS-CoV-2 through aerosols [21]. Because of their wide dispersion from their origin, increased suspension time, and extended transmission period, aerosols appear to pose the greatest risk of viral particle transmission. However, dilution and inactivation of viral particles, through factors such as temperature, humidity, and ventilation, can greatly diminish the risk of aerosol transmission [20].

2.2 Dynamics and Trajectories

2.2.1 Wells' Evaporation-Falling Curve

Much of our understanding of respiratory infection transmission as well as mitigation recommendations are derived from the Wells' evaporation-falling curve [19]. The Wells' evaporation-falling curve uses an expelled droplet's initial diameter to predict the time from droplet creation until evaporation, or the time from droplet creation until the droplet hits the ground. While this model greatly increased our understanding of disease transmission, due to its simplistic approach, the 2-meter (~6 feet) social distancing recommendation derived from the model may be an underestimation and too small of a distance to effectively mitigate COVID-19 transmission. Thus, alternative transmission models should be considered.

2.2.2 Turbulent Gas Cloud Theory

Turbulent Gas Cloud Theory states that droplets in exhalations, sneezes and coughs, instead of moving separately, move as a cluster resulting in a cloud with a forward momentum that propels the particles forward [22]. This model leads to two key findings: 1) droplets can travel much further than 2 meters (upwards of 8 meters), and 2) droplets vary more in size and thus vary more in viral load at any given distance from their origin, meaning higher viral loads can occur farther from their origins, increasing transmission risk.

3. Preventative Mitigation Measures

The World Health Organization (WHO) currently recommends multiple preventative practices to limit contraction of SARS-CoV-2: wear a mask when around others, maintain at least one meter between oneself and others, practice good hygiene, and avoid poorly ventilated environments [15]. Of these recommendations, masking, social distancing, hygiene, and locating an appropriate environmental setting are user-controlled behaviors that we detail further in this review.

3.1 Face Mask Usage

Masks may be the most effective strategy for reducing transmission rates of SARS-CoV-2. Face masks' protection is two-fold: they protect a wearer by filtering incoming airborne particles and protect other individuals by trapping respiratory droplets exhaled by a wearer [18]. There are three main types of masks (Figure 1a): respirators, surgical masks, and cloth face coverings.

Respirators are masks designed to achieve a very close facial fit by forming a seal around the nose and mouth to prevent contaminants from infiltrating the mask. Filtering facepiece respirators are in high demand because of their ability to filter out high percentages of small airborne particles sized approximately 0.3 µm or larger (Figure 1b). In contrast, mainly due to its loose fit, surgical masks are less effective than respirators [23] (Figure 1b). The loose fit creates gaps above the nose and along the cheeks, allowing unfiltered air to leak in and out of the mask. Therefore, in any aerosol generating environment, N95s are recommended for the maximum protection against transmission. However, in non-aerosol generating environments, surgical masks have not been shown to be inferior to N95s in preventing the transmission of SARS. When properly worn, surgical masks are meant to help block potentially pathogen-containing splashes or sprays from reaching the wearer [23]. These masks also help reduce the transfer of the wearer's respiratory secretions to others. Therefore, in cases of extreme respirator shortage, surgical masks may be used by the medical community in low risk, patient care settings to preserve respirators.

The Centers for Disease Control and Prevention (CDC) advises the use of cloth face coverings to slow the spread of the virus as an alternative to the limited healthcare grade PPE such as respirators and surgical masks [14]. Cloth face coverings include cloth masks, polyester masks, knitted masks, bandanas, and neck gaiters (Figure 1a). Face coverings are largely intended to trap the wearer's saliva and respiratory secretions from contaminating others; they do not fully protect the wearer from outside factors. Particular combinations of different fabrics and multiple fabric layers can lead to high filtration efficacy, similar to surgical masks [24]. However, because of varying filtration efficiencies, face coverings do not always protect wearers from airborne particles or droplets.

To quantify the effectiveness of community face mask usage, Chu et al. conducted a meta-analysis involving 172 observational studies [25]. They found that not wearing a face mask produced a 17.4% chance of viral infection compared to a 3.1% chance of viral infection in the intervention groups wearing face masks [25]. Face masks worn in this study include N95 respirators, disposable surgical masks, 12-16 layered cotton masks, and equivalent masks [25].

3.2 Social Distancing

Social distancing is another effective way to minimize SARS-CoV-2 transmission [14]. SARS-CoV-2 spreads when an infected person coughs, sneezes, or talks, emitting droplets from their mouth or nose into the air, putting others at risk of infection [14]. By appropriate socially distancing, an individual decreases the risk of transmitting or contracting SARS-CoV-2. Social distancing is especially important because asymptomatic individuals may unknowingly infect others.

Both social distancing and stay-at-home orders minimize contact with other individuals and reduce disease transmission. A meta-analysis found that social distancing resulted in a 10.2%

reduction in viral infection probability [25]. Furthermore, Thu et al. quantified the effectiveness of social distancing in several countries in which varying levels of social distancing guidelines (Table 1) were implemented [26]. This analysis demonstrated that the number of COVID-19 infections decreased according to the level of such measures. For instance, countries with Level 3 and 4 restrictions (e.g., Germany, Iran) demonstrated the most rapid drop in the number of daily cases following implementation [26]. This finding is consistent with an early modelling analysis that predicted social distancing measures would be extremely effective in reducing daily case numbers [26]. Additionally, a study that isolated the effects of social distancing measures on SARS-CoV-2 transmission in the United States found an 8.6 percent reduction in COVID-19 case growth rate after 21 days of implemented social distancing measures [27].

3.3 Hygiene

SARS-CoV-2 transmission may also occur as a result of touching fomites and transferring infected particles to an individual's respiratory tract [28]. Recent studies have shown that approximately 42-44% of all face touches occur in proximity to a mucous membrane, an entry point for the virus [28]. Even if frequently disinfected, contaminated surfaces pose a risk to the public. A recent study found that 44 out of 112 sites in hospital rooms occupied by asymptomatic individuals were deemed positive for the virus, even with frequent cleaning and disinfection [29]. To lower the possibility of transmission, frequent hand washing should be performed with soap and water for at least 20 seconds and disinfectants should contain an Alcohol-Based Hand Rub (ABHR) with 60-95% alcohol [14]. The percentage of alcohol in disinfectants is critical, as disinfectants with an alcohol concentration below 50% demonstrate minimal biocidal activity [30]. However, excessive hand washing and disinfection could also increase the probability of infection. In healthcare workers who washed their hands more than 10 times daily, 76.6% of participants reported skin damage, creating potential openings for pathogens [31]. Excessive use of alcohol disinfectants has similarly been shown to lead to antimicrobial resistance and dry and damaged skin [32]. For these reasons, it is important to moderate handwashing and disinfection times while remaining cognizant of surfaces touched.

3.4 Environmental Setting

Several environmental factors, especially physical setting, temperature, and humidity, influence the risk of SARS-CoV-2 transmission.

Indoor, closed, and poorly ventilated settings create a high risk of transmission while outdoor or well-circulated settings pose a lower risk [14]. The reasons for this distinction are two-fold. First, in outdoor settings, it is more feasible to ensure social distancing compared to indoor settings with limited space [14]. Second, indoor settings with low ventilation are confined environments, which increase the probability of transmission through airborne droplets and aerosols, even during normal speaking [33]. Ventilating indoor spaces with air from outside a room can decrease SARS-CoV-2 viral particle concentrations inside, reducing the risk to individuals in the room [34]. Methods of increasing ventilation include opening doors and windows and implementing HVAC (heating, ventilation, and air conditioning) systems with filters approved by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [34]. HVAC systems that provide high air change rates are especially effective in removing airborne contaminants [14]. In general, as the air change rate doubles, the time required for removal of airborne particles decreases by ~50% [14] (Table 2).

Air cleaning systems, such as HEPA (High Efficiency Particulate Air) filters, that remove particles of sizes 0.1-1 microns from the air, are often useful additions to HVAC systems [34]. HEPA filters can both filter viral particles from the air in a room and create a negative pressure that limits the spread of particles into neighboring spaces [35]. However, because the placement of HEPA filters, changes in their efficacy over time, and room-specific features play significant roles in determining their overall efficacy, accurately gauging their impact on transmission is an ongoing challenge [35].

Environmental temperature and relative humidity (RH) additionally impact transmission risk, as both alter SARS-CoV-2 stability [36]. The half-life of SARS-CoV-2 at 24°C ranges from 6.3 hours to 18.6 hours as RH decreases [36]. Strikingly, the half-life at 35°C ranges from only 1.0 hour to 8.9 hours over the same RH range [36]. One way that humidity affects transmission risk is through the rate of evaporation of virus-containing respiratory droplets [19], as per the Well's model (Figure 2). For example, the time to evaporate is approximately 35 seconds at RH=90%

but approximately 13 seconds at RH=30% (Figure 2). These results suggest that maintaining a higher temperature and humidity in various settings may help mitigate the risk of transmission of SARS-CoV-2. Table 3 summarizes how increasing ventilation, temperature and relative humidity results in a reduction in viral particles or viral half-life.

4. Proactive Mitigation Measures

While preventative mitigation measures deter transmission directly, proactive mitigation measures, such as testing and contact tracing, indirectly allow for interventions to mitigate transmission.

4.1 Testing

Testing for SARS-CoV-2 is one of the most effective measures to mitigate the transmission of the virus [37]. Fast, accurate testing provides both valuable insights regarding the rate of transmission and locations with high infection rates, and offers a strategy to detect asymptomatic carriers. According to the CDC, there are currently two kinds of testing available: 1) a viral test which detects current infection and 2) a test which checks the patient's blood for SARS-CoV-2 antibodies as a sign of previous infection [14]. The following sections aim to review each of these tests in more detail and acknowledge some of the current challenges to understanding and performing testing.

4.1.1 Viral Test

There are two main types of viral tests: molecular tests and antigen tests [23]. Molecular tests can directly detect infection by amplifying viral SARS-CoV-2 RNA present in a nasal swab or saliva sample through a reverse transcription polymerase chain reaction (RT-PCR) [23,38]. According to one study, the probability of a false negative from a molecular test decreases from 100% on the first day of infection to a median low of 20% on the eighth day of infection before increasing once more [39]. Results may take up to a few days before reaching the patient [23].

Antigen tests work by detecting specific proteins on the SARS-CoV-2 virion from a nasal swab sample [23]. Results are delivered in less than an hour [23]. With this test, the probability of a false negative for symptomatic individuals is roughly 20% and the probability for asymptomatic individuals is around 59% [40].

As of February 14, 2021, there are also alternative viral tests including combination testing which detects both influenza and coronavirus and prescription at-home testing which allows patients to safely collect and mail samples for testing [23].

4.1.2 Antibody Test

A normal response to infection is the production of antibodies by the infected individual's immune system. These antibodies can bind to viral surface antigens to prevent the virus from binding and entering cells to replicate its genetic material, thus leading to a cessation of the infection [41]. SARS-CoV-2 antibodies can be detected in roughly 20 minutes with a few drops of a previously infected individual's blood through either enzyme-linked immunosorbent assay (ELISA) tests or near-patient lateral flow devices [38]. However, these tests only provide a positive result multiple days after an individual has become infected when antibodies form [38]. The probability of a false negative ranges from 0% - 30% depending on the study [42]. Since more work needs to be done to understand the accuracy of antibody tests and the level of immunity provided by SARS-CoV-2 antibodies, the FDA encourages all individuals who test positive for antibodies to continue following the aforementioned mitigation measures [23].

4.2 Contact Tracing

Another proactive mitigation measure is contact tracing. After an individual has tested positive for SARS-CoV-2, close contacts that the individual may have infected are identified. The CDC defines a close contact as "someone who was within 6 feet of an infected person for a cumulative total of 15 minutes or more over a 24-hour period starting from 2 days before illness onset (or, for asymptomatic patients, 2 days prior to test specimen collection) until the time the patient is isolated" [14]. Traditionally, manual contact tracing includes healthcare workers interviewing infected individuals by phone, at home, or in hospitals. Afterwards, tracers contact the infected individual's close contacts, encouraging them to quarantine and to get tested [43]. Contact tracing is especially important in pre-symptomatic or asymptomatic individuals where close contacts would have little reason to believe they may be at risk of infection.

The measured impact of contact tracing has been validated in various international studies. For example, as of August 26, 2020, among the 487 confirmed cases in Taiwan, 42 were secondary cases, 37 (88%) of which were detected by contact tracing [44]. Another retrospective study in Shenzhen, China found that contact tracing reduced the time taken to isolate symptomatic cases by 58%, from 4.6 to 1.9 days on average [45].

Contact tracing during a pandemic places a large logistical and labor-intensive burden on public health workers. Keeling et al. concluded that on average, each case requires 36 individuals to be traced, with 8.7% of all cases having more than 100 close traceable contacts [46]. These numbers can be difficult to keep up with, even for a large agency with a sizable staff capacity [47].

Given the slow, laborious, and oftentimes inefficient nature of the traditional contact tracing process, digital solutions are in development [43]. Contact tracing applications have already been introduced in China, South Korea, and Italy [43]. An Italian app Immuni, launched in June of 2020, logs the user's location data using GPS or Bluetooth to determine whether two devices were close enough for their users to transmit the virus. After an individual's infection is reported, the app notifies other users who had been in close proximity [43]. While these apps helped the regions achieve sustained epidemic suppression, ethical and privacy concerns regarding user data have been raised. Jay Stanley and Jennifer Stisa Granick of the ACLU assert that location data contains an "enormously invasive and personal set of information" with the possibility to reveal "people's social, sexual, religious, and political associations," concluding that the "potential for invasions of privacy, abuse, and stigmatization is enormous" [48]. As a result, governments and agencies are faced with the difficult task of balancing personal privacy with public health. Possible solutions to this dilemma include anonymizing user information and specific location data, allowing each user's personal device to recognize possible exposures with no central data maintenance [49].

5. Summary and Conclusions

After quantitatively evaluating preventative mitigation methods (i.e., face mask usage, social distancing, proper hygiene, and choice of environment setting), and proactive mitigation methods (i.e., testing and contact tracing), we now qualitatively compare these mitigation strategies. A summary of the features, benefits, and drawbacks are provided in Table 4. Face coverings directly limit the spread of SARS-CoV-2 by trapping expelled respiratory droplets and filtering incoming airborne particles, but mask efficacy must be balanced with availability. While the most effective masks are in short supply and reserved for healthcare workers, less effective cloth face coverings are in high supply, comfortable, and provide a useful option for the general community. In comparison, social distancing may be less effective than respirators in directly mitigating disease transmission, but it is highly accessible and not subject to market supply issues. However, social distancing does limit social interaction, and thus may impact education, workplace efficiency, and general mental health. Hygiene is similar in that it's not as dependent on limited market supply, but hygiene alone is unlikely to sufficiently prevent airborne disease transmission. In contrast, controlling environmental settings (with HEPA filters), testing, and contact tracing are all highly effective practices, but typically require collective action and significant costs versus the individual activity of mask usage, social distancing, and proper hygiene.

Despite significant technological advances in mitigation measures (e.g., mobile apps for contact tracing and innovative mask designs), these measures are not effective unless 1) organizations successfully deploy them and 2) users comply with them. Implementation of multiple mitigation measures has previously been limited by a lack of capital resources, human resources and/or public support [50]. There is a need for comprehensive, quantitative studies comparing combinations of the aforementioned mitigation measures to inform governments and agencies on which would be the most effective and feasible to enact.

As demonstrated by countries such as New Zealand, a combination of proper implementation of mitigation measures and user compliance is feasible and can successfully eliminate transmission. The COVID-19 pandemic, due to the high communicability of SARS-CoV-2, has emphasized the importance of strategic deployment and widespread compliance with effective mitigation interventions to combat the transmission of infectious respiratory diseases.

Acknowledgements

We would like to acknowledge Nicholas Jeffreys, Nishant Sule, the Harvard Face Mask Committee, and the Harvard Active Learning Labs for providing excellent guidance throughout our investigation process. We would especially like to acknowledge Harvard Face Mask Committee members Stephen Blacklow, John Doyle, Willy Shih, Mary Corrigan, Sarah Fortune, and Sara Malconian for their invaluable support and advice. We would also like to recognize Alena Blaise, Jordan Daigle, Jose Gonzalez, Evan Hunsicker, Katia Osei, and Taisa Kulyk for their contributions during the Harvard SEAS engineering design course.

Declaration of Competing Interest

The authors declare no competing interests.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

[1] Dong E, Du H, Gardner L (2020) An interactive web-based dashboard to track COVID-19 in real time. Lancet Inf Dis 20(5):533-4. https://doi.org/10.1016/S1473-3099(20)30120-1

[2] Ranney ML, Griffeth V, Jha AK (2020) Critical Supply Shortages — The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic. N Engl J Med 382(18):e41. https://doi.org/10.1056/NEJMp2006141

[3] Remuzzi A, Remuzzi G (2020) COVID-19 and Italy: what next? Lancet 395(10231):1225-8. https://doi.org/10.1016/S0140-6736(20)30627-9

[4] Walker PGT, Whittaker C, Watson OJ, Baguelin M, Winskill P, Hamlet A, Djafaara BA et al (2020) The impact of COVID-19 and strategies for mitigation and suppression in low- and middle- income countries. Science 369(6502):413-22. https://doi.org/10.1126/science.abc0035

[5] Sanche S, Lin YT, Xu C, Romero-Severson E, Hengartner N, Ke R (2020) High Contagiousness and Rapid Spread of Severe Acute Respiratory Syndrome Coronavirus 2. Emerg Infect Dis 26(7):1470-7. https://doi.org/10.3201/eid2607.200282

[6] Nicola M, O'Neill N, Sohrabi C, Khan M, Agha M, Agha R (2020) Evidence based management guidelines for the COVID-19 pandemic. Int J Surg 77:206-16. https://doi.org/10.1016/j.ijsu.2020.04.001

[7] Baker MG, Wilson N, Anglemyer A (2020) Successful Elimination of Covid-19 Transmission in New Zealand. N Engl J Med 383(8):e56. https://doi.org/10.1056/NEJMc2025203

[8] Baker MG, Kvalsvig A, Verrall AJ, Telfar-Barnard L, Wilson N (2020) New Zealand's elimination strategy for the COVID-19 pandemic and what is required to make it work. N Z Med J 133(1512):10-4.

[9] Harvard University (2021) Harvard University-wide COVID-19 Testing Dashboard. https://www.harvard.edu/coronavirus/testing-tracing/harvard-university-wide-covid-19-testing-dashboard. Accessed 14 February 2021

[10] Stanford University (2021) COVID-19 Health Alerts. https://healthalerts.stanford.edu/covid-19/covid-dashboard/. Accessed 14 February 2021

[11] Baden LR, El Sahly NM, Essink B, Kotloff K, Frey S, Novak R, et al (2020) Efficacy and Safety of the mRNA-1273 SARS-CoV-2 Vaccine. N Engl J Med 384(5):403-16. https://doi.org/10.1056/NEJMoa2035389

[12] Castells MC, Phillips EJ (2020) Maintaining Safety with SARS-CoV-2 Vaccines. N Engl J Med 384 (7):643-9. https://doi.org/10.1056/NEJMra2035343

[13] Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S et al (2020) Safety and Efficacy of the BNT162b2 mRNA COVID-19 Vaccine. N Engl J Med 383(27):2603-15. https://doi.org/10.1056/NEJMoa2034577

[14] CDC (2020) Centers for Disease Control and Prevention. https://www.cdc.gov/. Accessed 9 January 2021

[15] WHO (2021) World Health Organization. https://www.who.int/emergencies/diseases/novel-coronavirus-2019. Accessed 14 February 2021

[16] Augenbraun BL, Lasner ZD, Mitra D, Prabhu S, Raval S, Sawaoka H et al (2020) Assessment and mitigation of aerosol airborne SARS-CoV-2 transmission in laboratory and office environments. J Occup Environ Hyg 17(10):447-56. https://doi.org/10.1080/15459624.2020.1805117

[17] Bar-On YM, Flamholz A, Phillips R, Milo R (2020) SARS-CoV-2 (COVID-19) by the numbers. eLife 9: e57309. https://doi.org/10.7554/eLife.57309

[18] Mittal R, Ni R, Seo J (2020) The flow physics of COVID-19. Journal of Fluid Mechanics 894(8):10. https://doi.org/10.1017/jfm.2020.330

[19] Xie X, Li Y, Chwang ATY, Ho PL, Seto WH (2007) How far droplets can move in indoor environments – revisiting the Wells evaporation–falling curve. Indoor Air 17(3):211-25. https://doi.org/10.1111/j.1600-0668.2007.00469.x

[20] Jayaweera M, Perera H, Gunawardana B, Manatunge J (2020) Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. Environ Res 188:109819. https://doi.org/10.1016/j.envres.2020.109819

[21] Asadi S, Bouvier N, Wexler AS, Ristenpart WD (2020) The coronavirus pandemic and aerosols: Does COVID-19 transmit via expiratory particles? Aerosol Sci Technol 54(6):635-8. https://doi.org/10.1080/02786826.2020.1749229

[22] Bourouiba L (2020) Turbulent Gas Clouds and Respiratory Pathogen Emissions: Potential Implications for Reducing Transmission of COVID-19. JAMA 323(18):1837-8. https://doi.org/10.1001/jama.2020.4756

[23] FDA (2020) Food and Drug Administration. https://www.fda.gov/. Accessed 14 February 2021

[24] Konda A, Prakash A, Moss G A, Schmoldt M, Grant G D, Guha S (2020) Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. J Am Chem Soc 4(5):6339–47. https://doi.org/10.1021/acsnano.0c03252

[25] Chu DK, Akl EA, Duda S, Solo K, Yaacoub S, Schunemann HJ et al (2020) Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. Lancet 395(10242):1973-87. https://doi.org/10.1016/S0140-6736(20)31142-9

[26] Thu T, Ngoc P, Hai NM, Tuan LA (2020) Effect of the social distancing measures on the spread of COVID-19 in 10 highly infected countries. Sci Total Environ 742:140430. https://doi.org/10.1016/j.scitotenv.2020.140430

[27] Courtemanche C, Garuccio J, Le A, Pinkston J, Yelowitz A (2020) Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate. Health Aff (Millwood) 39(7):1237–46. https://doi.org/10.1377/hlthaff.2020.00608

[28] Przekwas A, Chen Z (2020) Washing Hands and the Face May Reduce COVID-19 Infection. Medical Hypotheses 144:110261. https://doi.org/10.1016/j.mehy.2020.110261

[29] Qifang B, Yosheng W, Shujiang M, Chenfei Y, Xuan Z, Zhen Z et al (2020) Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. Lancet Infect Dis 20(8):911-9. https://doi.org/10.1016/S1473-3099(20)30287-5

[30] Pradhan D, Biswasroy P, Kumar Naik P, Ghosh G, Rath G (2020) A Review of Current Interventions for COVID-19 Prevention. Archives of Medical Research 51(5):363–74. https://doi.org/10.1016/j.arcmed.2020.04.020

[31] Lan J, Song Z, Miao X, Li H, Li Y, Dong L et al (2020) Skin damage among health care workers managing coronavirus disease-2019. Journal of the American Academy of Dermatology 82(5):1215–6. https://doi.org/10.1016/j.jaad.2020.03.014

[32] Mahmood A, Eqan M, Pervez S, Alghamdi H. A, Tabinda A. B, Yasar A et al (2020) COVID-19 and frequent use of hand sanitizers; human health and environmental hazards by exposure pathways. Science of The Total Environment 742:140561. https://doi.org/10.1016/j.scitotenv.2020.140561

[33] Stadnytskyi V, Bax CE, Bax A, Anfinrud P (2020) The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. Proc Natl Acad Sci USA 117(22):11875–7. https://doi.org/10.1073/pnas.2006874117

[34] EPA (2020) Environmental Protection Agency. https://www.epa.gov/coronavirus/. Accessed 8 January 2020

[35] Mousavi ES, Godri Pollitt KJ, Sherman J, Martinello RA (2020) Performance analysis of portable HEPA filters and temporary plastic anterooms on the spread of surrogate coronavirus. Build Environ 183:107186. https://doi.org/10.1016/j.buildenv.2020.107186

[36] Biryukov J, Boydston JA, Dunning RA, Yeager JJ, Wood S, Reese AL et al (2020) Increasing Temperature and Relative Humidity Accelerates Inactivation of SARS-CoV-2 on Surfaces. mSphere 5(4):e00441-20. https://doi.org/10.1128/mSphere.00441-20

[37] Binnicker MJ (2020) Challenges and Controversies to Testing for COVID-19. J Clin Microbiol 58(11):e01695-20. https://doi.org/10.1128/JCM.01695-20

[38] Beeching NJ, Fletcher TE, Beadsworth MJ (2020) Covid-19: Testing times. BMJ 369:m1403. https://doi.org/10.1136/bmj.m1403

[39] Kucirka L, Medicine J, Lauer S, Laeyendecker O, Boon D, Lessler J (2020) Variation in False-Negative Rate of Reverse Transcriptase Polymerase Chain Reaction–Based SARS-CoV-2 Tests by Time Since Exposure. Ann Intern Med 173(4):262-7. https://doi.org/10.7326/M20-1495

[40] Pray IW, Ford L, Cole D, Lee C, Bigouette JP, Abedi GR, et al (2021) Performance of an Antigen-Based Test for Asymptomatic and Symptomatic SARS-CoV-2 Testing at Two University Campuses - Wisconsin, September-October 2020. MMWR 69(51-52):1642-7. https://doi.org/10.15585/mmwr.mm695152a3

[41] French MA, Moodley Y (2020) The role of SARS-CoV-2 antibodies in COVID-19: Healing in most, harm at times. Respirology 25(7):680-2. https://doi.org/10.1111/resp.13852

[42] Robert H, Shmerling M (2021) Which test is best for COVID-19? https://www.health.harvard.edu/blog/which-test-is-best-for-covid-19-2020081020734#:~:text=Having%20an%20antibody%20test%20too,negatives%20is%2020%25. Accessed 22 January 2021

[43] Tibbetts JH (2020) Researchers Continue Quest to Contain Spread of COVID-19. BioScience 70(8):633-9. https://doi.org/10.1093/biosci/biaa071

[44] Jian SW, Cheng HY, Huang XT, Liu DP (2020) Contact tracing with digital assistance in Taiwan's COVID-19 outbreak response. Int J Infect Dis 101:348-52. https://doi.org/10.1016/j.ijid.2020.09.1483

[45] Bi Q, Wu Y, Mei S, Zou X, Zhang Z, Liu X, et al (2020) Epidemiology and Transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. Lancet Infect Dis 20(8):911-9. https://doi.org/10.1016/S1473-3099(20)30287-5

[46] Keeling MJ, Hollingsworth TD, Read JM (2020) Efficacy of contact tracing for the containment of the 2019 novel coronavirus (COVID-19). J Epidemiol Community Health 74(10):861-6. https://doi.org/10.1136/jech-2020-214051

[47] Kalyanaraman N, Fraser MR (2021) Containing COVID-19 Through Contact Tracing: A Local Health Agency Approach. Public Health Rep 136(1):32-8. https://doi.org/10.1177/0033354920967910

[48] Stanley J, Granick JS (2020) The Limits of Location Tracking in an Epidemic. https://www.aclu.org/sites/default/files/field_document/limits_of_location_tracking_in_an_epidemic.pdf. Accessed 14 February 2021

[49] Kapa S, Halamka J, Raskar R (2020) Contact Tracing to Manage COVID-19 Spread—Balancing Personal Privacy and Public Health. Mayo Clin Proc 95(7):1320-2. https://doi.org/10.1016/j.mayocp.2020.04.031

[50] Anderson RM, Heesterbeek H, Klinkenberg D, Hollingsworth TD (2020) How will country-based mitigation measures influence the course of the COVID-19 epidemic? Lancet 395(10228):931-4. https://doi.org/10.1016/S0140-6736(20)30567-5

Figures

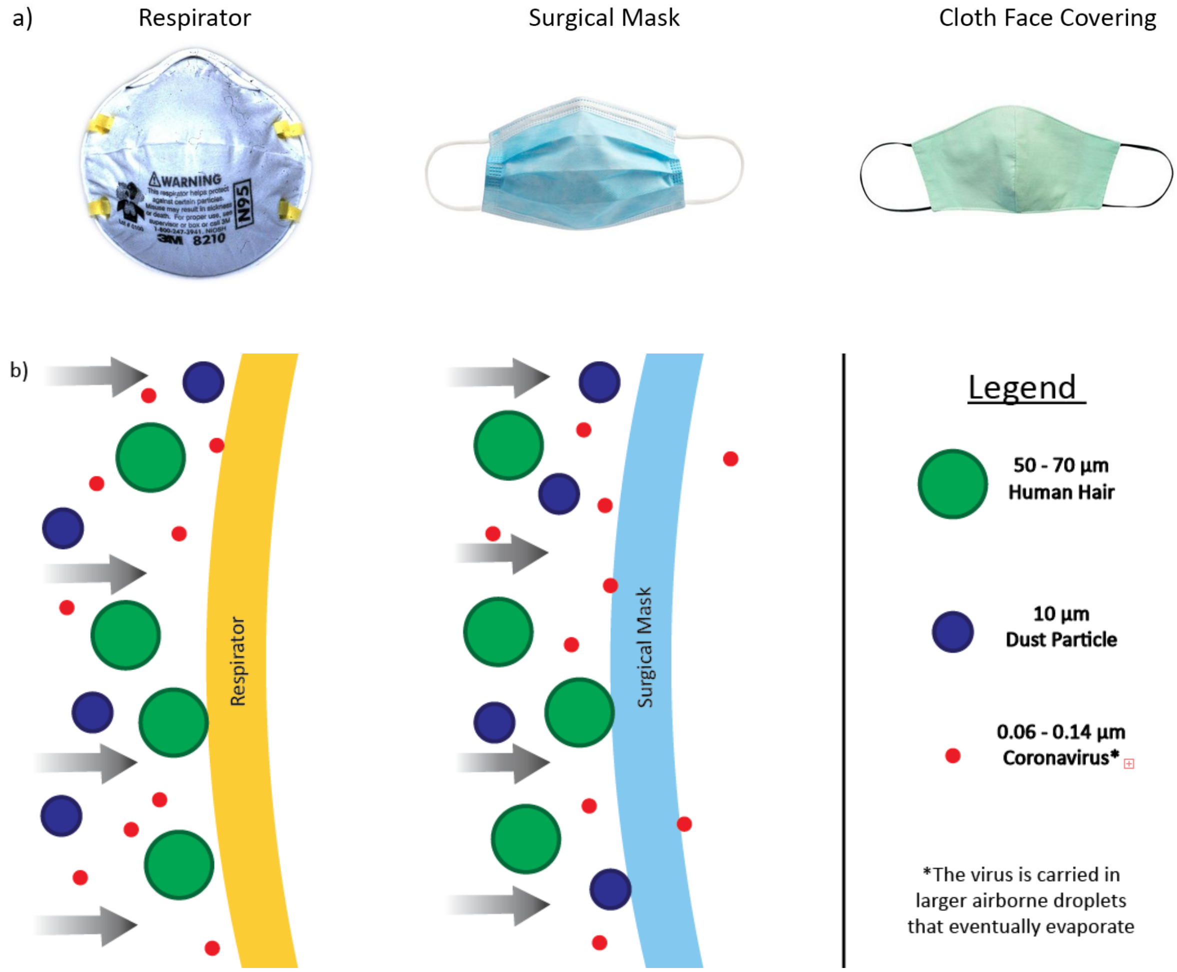

Fig. 1 a) Examples of the three main types of face masks b) A comparison of the filtration efficiency between a surgical mask and a respirator using various size particles.

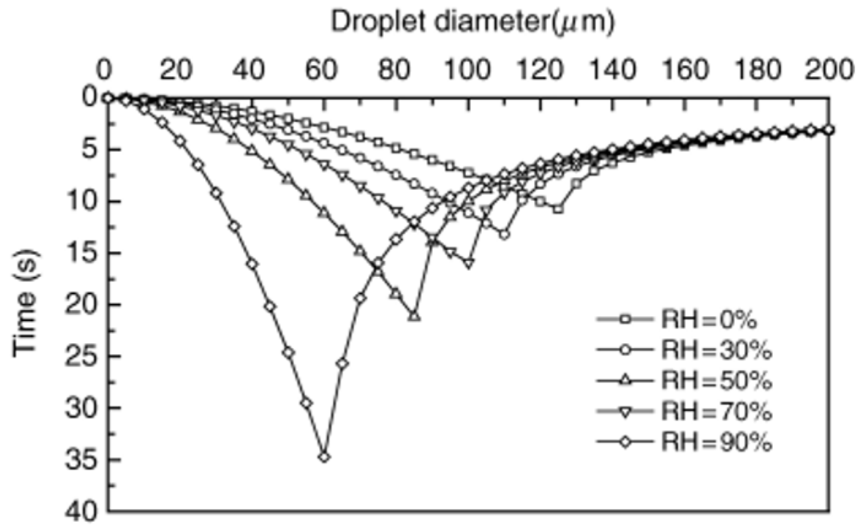

Fig. 2 The Wells' evaporation-falling curve depicting time until droplet evaporation and the time from droplet creation until the droplet hits the ground. Each curve represents changes due to relative humidity (RH). The downward arc of each curve presents the time until droplet evaporation; the upward arc of each curve predicts the time from droplet creation until the droplet hits the ground. Time (s) refers to time until evaporation. Adapted from "How far droplets can move in indoor environments - revisiting the Wells evaporation-falling curve" (Xie et al. 2007).

Tables

Table 1: Levels of social distancing [46].

Level 1	Warnings against going out by region, which is the lightest level, only promulgated on specific areas affected by the spread of virus.
Level 2	Warnings against going out on a nationwide scale.
Level 3	Stay-at-home measures by region. This measure prevents people in highly affected regions from going outside with very few exceptions, including shopping for basic necessities or seeking medical help.
Level 4	Stay-at-home measures on a nationwide scale. Everyone in the country is required to stay home unless it is absolutely vital for them to go out. This measure is similar to Level 3, but on a bigger scale in response to the national state of emergency.

Table 2: Time required for removal of airborne contaminants based on air change rates (CDC 2020).

Air Change per Hour (ACH)	Time (min) required for removal (99.0% efficiency)	Time (min) required for removal (99.9% efficiency)
2	138	207
4	69	104
6	46	69
8	35	52
10	28	41
12	23	35
15	18	28
20	14	21
50	6	8

Table 3: Environmental setting effect on viral stability [11,14].

Mitigation Method	Control Situation	% reduction in viral stability
Increasing Ventilation	2 ACH	50% decrease in time to remove 99% of viral particles with every 50% increase in ACH
Increasing Temperature	24°C at 20% RH	52% decrease in viral lifetime with increase to 35°C, 20% RH
Increasing Relative Humidity	20% RH at 24°C	46% decrease in viral lifetime with increase to 80% RH, 24°C

Table 4: Comparison of features, benefits, and drawbacks of mitigation methods detailed in this review.

Mitigation Method	Features	Benefits	Drawbacks
Face Mask Usage			
Respirators	- Filters >3μm airborne particles out and traps respiratory droplets - 95% or greater filtration rate - Tight fit	- Offers the most protection against transmission or contraction of SARS-CoV-2	- Limited supply reserved for healthcare personnel - Meant for one-time use - Requires annual fit testing in healthcare settings
Surgical Masks	- Filters larger airborne particles out and traps respiratory droplets - Loose fit	- Greater availability - Acts as a physical barrier to reduce the transmission or contraction of SARS-CoV-2	- Gaps in fit result in air leakage - Meant for one-time use
Cloth Face Coverings	- Traps respiratory droplets - Loose fit	- Greater availability - Reduces the transmission of SARS-CoV-2 - High comfort - Reusable	- Level of protection varies depending on number of layers and fabric - Poor filtration efficiency
Social Distancing			
Social Distancing	- At least 6 feet distance between individuals	- Limits potential transmission or contraction of SARS-CoV-2 through aerosols and droplets	- Fewer individuals in indoor spaces - Minimizes social contact between individuals
Hygiene			

Hygiene	- Frequent hand washing for 20 seconds - Frequent hand disinfection with disinfectants with an ABHR of 60-95% - Using gloves for high-risk public spaces	- Hand washing and disinfection has proven to inactivate and diminish SARS-CoV-2 particles	- Excessive hand washing and disinfection can ultimately damage a person's hands, creating wounds and openings for the virus to enter through - Excessive hand disinfection can lead to antimicrobial resistance
Environmental Setting			
Increasing Ventilation	- Adequate air exchange rates for each space (e.g., more effective HVAC systems) - Increase air filtration (e.g., addition of HEPA filters)	- Reduces viral concentration in air - Reduces time for viral load to dissipate from air - Reduces transmission risk	- Effect (esp. of HEPA filters) depends heavily on placement and room features - Quantifying exact magnitude of impact is complex
Increasing Temperature	- Increase temperature above room temperature (>24°C)	- Reduces stability/half-life of virus - Reduces transmission risk	- Increasing temperature may cause discomfort to those in the room - Difficult to control temperature in some settings
Increasing Relative Humidity	- Increase relative humidity (>20%)	- Reduces stability/half-life of virus - Reduces transmission risk	- Increasing humidity may cause discomfort to those in the room - Difficult to control humidity in many settings

Testing			
Testing	- Viral tests utilize a nasal or throat swab to detect current infection - Antibody tests utilize a finger stick or blood draw to detect previous infection	- Viral molecular tests are highly specific, with very few false positives - Viral antigen and antibody tests offer results in as quick as 20 minutes - At-home testing protects healthcare workers - All tests are capable of detecting infection in asymptomatic individuals	- Takes 1-3 weeks to develop enough antibodies for accurate results - Cost for patient is unpredictable
Contact Tracing			
Contact Tracing	- Alerting close contacts who may be at risk of contracting the virus	- When done swiftly, can reduce transmission rates - Identifies potential asymptomatic and presymptomatic cases	- Labor and time intensive - Ethical and privacy concerns