Airborne viral transmission & the effectiveness of masks / face coverings

Key points

- Viral RNA (based on coronaviruses) can be present in around 30% of droplets and 40% of aerosols.
- SARS-CoV-2 specifically can remain viable and infectious in respirable-sized aerosols for up to 16 hours, and its dynamic aerosol efficiency surpassed those of SARS-CoV-1 and MERS.
- Aerosol and droplets are highly likely to be a mode of transmission during breathing, speaking and light activity, including from asymptomatic individuals, and especially in confined environments.
- Proper ventilation is a key aspect for containment of the virus in indoor environments, since it substantially reduces the airborne time of respiratory droplets. This is relevant because typically poorly ventilated and populated spaces (e.g. public transport and nursing homes) have been reported as sites of viral transmission despite preventive physical distancing.
- Trials on caged hamsters using a fan, where infected hamsters were upwind and uninfected hamsters were downwind, showed that when no mask was used on the infected cage, 66.7% of uninfected hamsters were infected downwind, which reduced to 16.7% when a mask was added on the infected cage.
- Various studies showed a reduction in chance of viral transmission from 17.4% where no masks worn, to 3.1% with face masks in use.
- Field data from Germany showed an estimated reduction in the growth rates of infections by 40% to 60% which was solely attributed to introduction of mandatory mask wearing in public.
- Various commonly available fabrics used in cloth masks can potentially provide significant protection against the transmission of aerosol particles.
- The use of low efficacy masks (e.g. cloth masks with estimated efficacy less than 30%) could lead to significant reduction of COVID-19 burden (albeit, they are not able to lead to elimination). Combining low efficacy masks with improved levels of the other anti-COVID-19 intervention strategies can lead to the elimination of the pandemic.
- For society to resume, measures designed to reduce aerosol transmission must be implemented. This means mandated face coverings and widespread testing to identify and isolate infected asymptomatic individuals. Other mitigation measures, such as social distancing are insufficient by themselves in protecting the public.

A. Evidence of effectiveness of masks & face coverings

Research	Main lessons to take away
Leung, N.H.L. *et al* (2020) **Respiratory virus shedding in exhaled breath and efficacy of face masks.** *Nat Med* 26**,** 676–680 (2020). Published: 3 April, 2020. https://www.nature.com/articles/s41591-020-0843-2.pdf	*"We tested viral shedding (in terms of viral copies per sample) in nasal swabs, throat swabs, respiratory droplet samples and aerosol samples and compared the latter two between samples collected with or without a face mask…. Viral RNA was identified from respiratory droplets and aerosols for all three viruses, including 30%, 26% and 28% of respiratory droplets and 40%, 35% and 56% of aerosols collected while not wearing a face mask from coronavirus, influenza virus and rhinovirus-infected participants, respectively."* *"Our results indicate that aerosol transmission is a potential mode of transmission for coronaviruses as well as influenza viruses and rhinoviruses."* *"Surgical face masks significantly reduced detection of influenza virus RNA in respiratory droplets and coronavirus RNA in aerosols… Our results indicate that surgical face masks could prevent transmission of human coronaviruses and influenza viruses from symptomatic individuals."*
Chan, J. F.W. (2020) **Surgical mask partition reduces the risk of non-contact transmission in a golden Syrian hamster model for Coronavirus Disease 2019 (COVID-19).** *Clinical Infectious Diseases*, ciaa644. Published: 30 May, 2020. https://doi.org/10.1093/cid/ciaa644 https://fightcovid19.hku.hk/hku-hamster-research-shows-masks-effective-in-preventing-covid-19-transmission/ An excellent explanation is given in this video (starting (from 4'25" into vid): https://www.youtube.com/watch?v=zhQw7vLNsDA&feature=emb_logo	Research on hamsters showing that masks have an effect on the amount of non-contact transmission of COVID-19, as well as the viral load of those that do get infected. - When infected hamster cage was not masked, 66.7% of uninfected hamsters downwind were infected. - When uninfected hamsters cage was masked instead, 33.3% of hamsters downwind were infected. - When infected hamster cage was masked, 16.7% of uninfected hamsters downwind were infected. *"SARS-CoV-2 could be transmitted by respiratory droplets or airborne droplet nuclei in the hamster model. Such transmission could be reduced by surgical mask usage, especially when masks were worn by infected individuals."*
Mitze, T. *et al* (2020) ***Face Masks Considerably Reduce COVID-19 Cases in Germany: A Synthetic Control Method Approach.*** Discussion Paper Series, IZA DP No. 13319, Institute of Labour Economics, Bonn, Germany. Published: June, 2020.	*"We conclude from this literature review that our paper is the first analysis that provides field evidence on the effect of masks on mitigating the spread of Covid-19."* *"Our findings indicate that the early introduction of face masks in Jena has resulted in a reduction of almost 25% in the cumulative number of reported Covid-19 cases after 20*

https://www.iza.org/publications/dp/13319/face-masks-considerably-reduce-covid-19-cases-in-germany-a-synthetic-control-method-approach	*days. The drop is greatest, larger than 50%, for the age group 60 years and above."* *"This* [25% reduction] *corresponds to a reduction in the average daily growth rate of the total number of reported infections by 1.32 percentage points. Comparing the daily growth rate in the synthetic control group with the observed daily growth rate in Jena, the latter shrinks by around 60% due to the introduction of face masks. This is a sizeable effect. Wearing face masks apparently helped considerably in reducing the spread of Covid-19. Looking at single treatment effects for all other regions puts this result in some perspective. The reduction in the growth rate of infections amounts to 20% only. By contrast, when we take the multiple treatment effect for larger cities into account, we find a reduction in the growth rate of infections by around 40%. What would we reply if we were asked what the effect of introducing face masks would have been if they had been made compulsory all over Germany? The answer depends, first, on which of the three percentage measures we found above is the most convincing and, second, on the point in time when face masks are made compulsory. The second aspect is definitely not only of academic interest but would play a major role in the case of a second wave. We believe that the reduction in the growth rates of infections by 40% to 60% is our best estimate of the effects of face masks. The most convincing argument stresses that Jena introduced face masks before any other region did so. It announced face masks as the first region in Germany while in our post-treatment period no other public health measures were introduced or eased. Hence, it provides the most clear-cut experiment of its effects. Second, as stated above, Jena is a fairly representative region of Germany in terms of Covid-19 cases. Third, the smaller effects observed in the multiple treatment analysis may also result from the fact that −by the time that other regions followed the example of Jena− behavioral adjustments in Germany's population had also taken place. Wearing face masks gradually became more common and more and more people started to adopt their usage even when it was not yet required."*
Chu, D.K. *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.** *The Lancet*. Published: June 01, 2020.	Across 29 unadjusted studies and 10 adjusted studies, they showed a reduction in chance of viral transmission from 17.4% where no masks worn, to 3.1% with face masks in use. Large reduction for all mask types (N95, surgical, homemade multi-layer cotton masks). They also noted that N95 or similar had a larger effect, which is a finding that contradicted some previous studies.

https://www.thelancet.com/pdfs/journals/lancet/PIIS0140-6736(20)31142-9.pdf	*"Transmission of viruses was lower with physical distancing of 1 m or more, compared with a distance of less than 1 m;… protection was increased as distance was lengthened…. Face mask use could result in a large reduction in risk of infection, with stronger associations with N95 or similar respirators compared with disposable surgical masks or similar…. Eye protection also was associated with less infection."*
Zhang, R. *et al* (2020) **Identifying airborne transmission as the dominant route for the spread of COVID-19.** *Proceedings of the National Academy of Sciences,* Jun 2020, 202009637. Published: 11 June, 2020. https://www.pnas.org/content/early/2020/06/10/2009637117	*"Our results show that the airborne transmission route is highly virulent and dominant for the spread of COVID-19. The mitigation measures are discernible from the trends of the pandemic. Our analysis reveals that the difference with and without mandated face covering represents the determinant in shaping the trends of the pandemic. This protective measure significantly reduces the number of infections. Other mitigation measures, such as social distancing implemented in the United States, are insufficient by themselves in protecting the public. Our work also highlights the necessity that sound science is essential in decision-making for the current and future public health pandemics."* *"This protective measure alone* [mandated face covering] *significantly reduced the number of infections, that is, by over 78,000 in Italy from April 6 to May 9 and over 66,000 in New York City from April 17 to May 9."* *"Other mitigation measures, such as social distancing implemented in the United States, are insufficient by themselves in protecting the public. We conclude that wearing of face masks in public corresponds to the most effective means to prevent interhuman transmission, and this inexpensive practice, in conjunction with simultaneous social distancing, quarantine, and contact tracing, represents the most likely fighting opportunity to stop the COVID-19 pandemic."*
Prather, K.A. *et al* (2020) **Reducing transmission of SARS-CoV-2.** *Science*. Published: 27 May, 2020. https://science.sciencemag.org/content/early/2020/06/02/science.abc6197.1/tab-pdf	A succinct overview of various other research into efficacy of masks, and good explanation of difference between droplets and aerosols. *"…a large proportion of the spread of coronavirus disease 2019 (COVID-19) appears to be occurring through airborne transmission of aerosols produced by asymptomatic individuals during breathing and speaking. Aerosols can accumulate, remain infectious in indoor air for hours, and be easily inhaled deep into the lungs. For society to resume, measures designed to reduce aerosol transmission must be implemented, including universal masking and regular, widespread testing to identify and isolate infected asymptomatic individuals."*

	"From epidemiological data, places that have been most effective in reducing the spread of COVID-19 have implemented universal masking, including Taiwan, Japan, Hong Kong, Singapore, and South Korea. In the battle against COVID-19, Taiwan (population 24 million, first COVID-19 case 21 January 2020) did not implement a lockdown during the pandemic, yet maintained a low incidence of 441 cases and 7 deaths (as of 21 May 2020). By contrast, the state of New York (population ~20 million, first COVID case 1 March 2020), had a higher number of cases (353,000) and deaths (24,000). By quickly activating its epidemic response plan that was established after the SARS outbreak, the Taiwanese government enacted a set of proactive measures that successfully prevented the spread of SARS-CoV-2, including setting up a central epidemic command center in January, using technologies to detect and track infected patients and their close contacts, and perhaps most importantly, requesting people to wear masks in public places. The government also ensured the availability of medical masks by banning mask manufacturers from exporting them, implementing a system to ensure that every citizen could acquire masks at reasonable prices, and increasing the production of masks. In other countries, there have been widespread shortages of masks, resulting in most residents not having access to any form of medical mask. This striking difference in the availability and widespread adoption of wearing masks likely influenced the low number of COVID-19 cases."
Konda, A. *et al* (2020) **Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks.** *ACS Nano*, 2020 14 (5), 6339-6347. Published: 24 April, 2020. https://pubs.acs.org/doi/10.1021/acsnano.0c03252	The aerosol filtering efficiency of different materials, thicknesses, and layers used in properly fitted homemade masks was found to be similar to that of the medical masks that were tested. *"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."* Where combinations of different fabrics were used, the observed *"enhanced performance… 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."
Davies, A. *et al* (2013). **Testing the Efficacy of Homemade Masks: Would They Protect in an Influenza Pandemic?** *Disaster medicine and public health preparedness.* 7. 413-418. https://pubmed.ncbi.nlm.nih.gov/24229526/	*"Several household materials were evaluated for the capacity to block bacterial and viral aerosols."* *"Our findings suggest that a homemade mask should only be considered as a last resort to prevent droplet transmission from infected individuals, but it would be better than no protection."*
Robertson, P. (2020) **The Ultimate Guide to Homemade Face Masks for Coronavirus.** *Blog on SmartAir website.* Published online 21 April, 2020. https://smartairfilters.com/en/blog/best-diy-coronavirus-homemade-mask-material-covid/	They chose 3 times more materials than the study by Davies *et al* (2013). *"For 0.3-micron particles, there was a much wider range in effectiveness. The N95 mask, HEPA filter, and surgical mask still did best, all capturing over 75%. However, the materials consistently captured fewer smaller particles than larger particles. Among the household materials, the HERO coffee filter came up next in the list, capturing 62%. But only four other materials filtered more than 48%: the 40D nylon, CHEMEX coffee filter, the dish towel, and canvas."* *"Based on a combination of breathability and filtration effectiveness, the best materials for homemade masks are: Denim (10oz), Bed sheets (80-120 thread), Paper towel, Canvas (0.4-0.5mm thick), Shop towels."*
Verma, S. *et al* (2020) **Visualizing the effectiveness of face masks in obstructing respiratory jets.** *Phys. Fluids* 32, 061708 (2020). Published: 30 June, 2020. https://doi.org/10.1063/5.0016018	A study on effectiveness of 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."* *"Importantly, uncovered emulated coughs were able to travel notably farther than the currently recommended 6-ft distancing guideline."*
Ngonghala, C.N. *et al* (2020) **Mathematical assessment of the impact of non-pharmaceutical interventions on curtailing the 2019 novel Coronavirus.** *Mathematical Biosciences*, 325 (2020) 108364.	The study was based on simulations of a new mathematical model in order to better understand transmission dynamics and control of COVID-19 in a community. *"In summary, our study suggests that, like in the case of the other Coronaviruses we have seen in the past (namely SARS and MERS), COVID-19 is a pandemic that appears to be*

Published: 1 May, 2020. https://www.sciencedirect.com/science/article/pii/S0025556420300560	*controllable using basic non-pharmaceutical interventions, particularly social-distancing and the use of face-masks in public (especially when implemented in combinations)."* *"This study shows that early termination of the strict social-distancing measures could trigger a devastating second wave with burden similar to those projected before the onset of the strict social-distancing measures were implemented. The use of efficacious face-masks (such as surgical masks, with estimated efficacy ≥ 70%) in public could lead to the elimination of the pandemic if at least 70% of the residents of New York state use such masks in public consistently (nationwide, a compliance of at least 80% will be required using such masks). The use of low efficacy masks, such as cloth masks (of estimated efficacy less than 30%), could also lead to significant reduction of COVID-19 burden (albeit, they are not able to lead to elimination). Combining low efficacy masks with improved levels of the other anti-COVID-19 intervention strategies can lead to the elimination of the pandemic. This study emphasizes the important role social-distancing plays in curtailing the burden of COVID-19."* *"Using face-masks in public (including the low efficacy cloth masks) is very useful in minimizing community transmission and burden of COVID-19, provided their coverage level is high. The masks coverage needed to eliminate COVID-19 decreases if the masks-based intervention is combined with the strict social-distancing strategy."*

B. Evidence of airborne transmission

Lednicky, J.A. *et al* (2020) **Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients.** *medRxiv*, 2020.08.03.20167395. Published: 4 August, 2020. https://www.medrxiv.org/content/10.1101/2020.08.03.20167395v1	*"Viable virus was isolated from air samples collected 2 to 4.8m away from the patients. The genome sequence of the SARS-CoV-2 strain isolated from the material collected by the air samplers was identical to that isolated from the NP swab from the patient with an active infection. Estimates of viable viral concentrations ranged from 6 to 74 $TCID_{50}$ units/L of air."* *"Patients with respiratory manifestations of COVID-19 produce aerosols in the absence of aerosol-generating procedures that contain viable SARS-CoV-2, and these aerosols may serve as a source of transmission of the virus."*
de Man, P. *et al* (2020) **Outbreak of COVID-19 in a nursing home associated with aerosol transmission as a result of inadequate ventilation.**	*"In total, 17 (81%) residents from one of the seven wards in a nursing home with psychogeriatric residents were diagnosed with COVID-19 as confirmed by RT-PCR... Subsequently, 17 (50%) healthcare workers (HCWs) of the same ward were also tested positive. In contrast, all tests of*

Clinical Infectious Diseases, ciaa1270. Manuscript accepted: 28 August, 2020 https://doi.org/10.1093/cid/ciaa1270	*the 106 HCWs or 95 residents in the 6 other wards were negative."* *"This ward* [the one with the positive cases] *was renovated, including the installation of a CO_2 controlled energy-efficient ventilation system… If the CO_2 concentration did not exceed 1000 ppm, the ventilation cabinets recirculated indoor air back into the ward without filtration… Moreover, this ward was additionally cooled by two air conditioning units, which recirculated air through a 1 mm mesh dust filter. In contrast, the other six wards were ventilated with outside air."* *"Our data suggest that this outbreak is caused by aerosol transmission of COVID-19 in a situation of inadequate ventilation for several reasons. First, the near simultaneous detection of COVID-19 infections of almost all residents HCWs within a ward in which care was provided with surgical masks. Second, the limitation of the outbreak to this particular ward with a deviating ventilation system that recirculated unfiltered inside air in combination with the detection of COVID-19 on the filters of this system. Finally, the outbreak in this nursing home emerged in a period of low back ground prevalence of COVID19 infections in the community. We advise that prevention of COVID-19 transmission should take into account the possibility of aerosol transmission in healthcare facilities and other buildings where ventilation systems recirculate unfiltered inside air."*
Klompas, M. *et al* (2020) **Airborne transmission of SARS-CoV-2: theoretical considerations and available evidence.** *JAMA*, 2020;324(5):441–442. Published: 13 July, 2020 https://jamanetwork.com/journals/jama/fullarticle/2768396	*"Demonstrating that speaking and coughing can generate aerosols or that it is possible to recover viral RNA from air does not prove aerosol-based transmission; infection depends as well on the route of exposure, the size of inoculum, the duration of exposure, and host defenses."* *"It is impossible to conclude that aerosol-based transmission never occurs and it is perfectly understandable that many prefer to err on the side of caution, particularly in health care settings when caring for patients with suspected or confirmed COVID-19. However, the balance of currently available evidence suggests that long-range aerosol-based transmission is not the dominant mode of SARS-CoV-2 transmission."*
Morawska, L.; Cao, J. (2020) **Airborne transmission of SARS-CoV-2: The world should face the reality**. *Environment International*, Volume 139 (2020) 105730. Published: 10 April, 2020.	*"One transmission route that is mentioned only in passing, or not at all, is the transport of virus-laden particles in the air. Immediately after droplets are expired, the liquid content starts to evaporate, and some droplets become so small that transport by air current affects them more than gravitation. Such small droplets are free to travel in the air*

https://www.sciencedirect.com/science/article/pii/S016041202031254X	*and carry their viral content meters and tens of meters from where they originated."* *"Is it likely that the SARS-CoV-2 virus spreads by air? Its predecessor, SARS-CoV-1, did spread in the air. This was reported in several studies and retrospectively explained the pathway of transmission in Hong Kong's Prince of Wales Hospital (Li et al., 2005, Xiao et al., 2017;12., Yu et al., 2005), as well as in health care facilities in Toronto, Canada (Booth et al. 2005), and in aircraft (Olsen et al. 2003). These studies concluded that airborne transmission was the main transmission route in the indoor cases studied."* *Considering the many similarities between the two SARS viruses and the evidence on virus transport in general, it is highly likely that the SARS-CoV-2 virus also spreads by air... Therefore, all possible precautions against airborne transmission in indoor scenarios should be taken.... personal protective equipment (PPE), in particular masks and respirators should be recommended, to be used in public places where density of people is high and ventilation potentially inadequate, as they can protect against infection [of] others (by infected individuals) and being infected."* *"It is difficult to explain why public health authorities marginalize the significance of airborne transmission of influenza or coronaviruses, but a possible reason is that it is difficult to directly detect the viruses traveling in the air."* *"Despite the evidence and strong hypotheses, the world appears to be locked in the old way of thinking that only direct contact matters in viral infection spread."*
Asadi, S. *et al* (2020) **The coronavirus pandemic and aerosols: Does COVID-19 transmit via expiratory particles?** *Aerosol Science and Technology*, 54:6, 635-638. Published: 3 April, 2020. https://www.tandfonline.com/doi/full/10.1080/02786826.2020.1749229	*"Asymptomatic and pre-symptomatic individuals, by definition, do not cough or sneeze to any appreciable extent. This leaves direct or indirect contact modes and aerosol transmission as the main possible modes of transmission. Much media attention has correctly focused on the possibility of direct and indirect transmission via for example contaminated hands, with public health messages focusing on the importance of washing hands thoroughly and often, and of greeting others without shaking hands. Less attention has focused on aerosol transmission, but there are important reasons to suspect it plays a role in the high transmissibility of COVID-19. Air sampling performed by Booth et al. (2005) established that hospitalized patients infected with SARS during the 2003 epidemic emitted viable aerosolized virus into the air. Notably, that outbreak was caused by SARS-CoV-1, the closest known relative in humans to the SARS-CoV-2 virus responsible for the current pandemic. These viruses are not the same, but recent*

	experimental work by van Doremalen et al. (2020) demonstrated that aerosolized SARS-CoV-2 remains viable in the air with a half-life on the order of 1 h; they concluded that both "...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." *"Much media attention has correctly focused on the possibility of direct and indirect transmission via for example contaminated hands, with public health messages focusing on the importance of washing hands thoroughly and often, and of greeting others without shaking hands. Less attention has focused on aerosol transmission, but there are important reasons to suspect it plays a role in the high transmissibility of COVID-19."* *"...we argue here that speech plausibly serves as an important and under-recognized transmission mechanism for COVID-19."*
van Doremalen, N. *et al* (2020) **Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1.** Letter, *N Engl J Med*. 2020; 382:1564–7. Published: 17 March, 2020. https://www.nejm.org/doi/pdf/10.1056/NEJMc2004973?articleTools=true	*"SARS-CoV-2 remained viable in aerosols throughout the duration of our experiment (3 hours), with a reduction in infectious titer from 103.5 to 102.7 TCID50 per liter of air. This reduction was similar to that observed with SARS-CoV-1, from 104.3 to 103.5 TCID50 per milli-liter".* *"Our results indicate that 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."*
NHK documentary (starting 28 mins to 39 mins): Posted online: 2 April, 2020. https://www.youtube.com/watch?v=I7_1DackmWI	Experiment tracking micro-droplets in the air from sneezing and talking, using laser beams and a high-sensitivity camera. *"It's not yet known what volume of micro-droplets leads to infection, but Tatada says we can't rule out the possibility that micro-droplets have spread the virus to some extent."* *"Micro-droplets carry many viruses. We produce them when we talk loudly or breathe heavily. People around us inhale them, and that's how the virus spreads. We're beginning to see this risk now."*
Liu, Y. *et al* (2020) Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. *Nature*. Published: 27 April, 2020. https://doi.org/10.1038/s41586-020-2271-3	*"The concentration of SARS-CoV-2 RNA in aerosols detected in isolation wards and ventilated patient rooms was very low, but it was elevated in the patients' toilet areas. Levels of airborne SARS-CoV-2 RNA in the majority of public areas was undetectable except in two areas prone to crowding."* *"Although we have not established the infectivity of the virus detected in these hospital areas, we propose that SARS-CoV-2 may have the potential to be transmitted via aerosols. Our results indicate that room ventilation, open*

	space, sanitization of protective apparel, and proper use of disinfection of toilet areas can effectively limit the concentration of SARS-CoV-2 in aerosols." *"The results… reinforce the importance of avoiding crowded gatherings and implementing early identification and diagnosis of infected carriers for quarantine or treatment."*
Stadnytskyi, V. *et al* (2020) The airborne lifetime of small speech droplets and their potential importance in SARS-CoV-2 transmission. *Proceedings of the National Academy of Sciences*, Jun 2020, 117 (22) 11875-11877. Published: 13 May, 2020. https://www.pnas.org/content/117/22/11875.long	*"Speech droplets generated by asymptomatic carriers of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) are increasingly considered to be a likely mode of disease transmission."* *"In a closed, stagnant air environment, they disappear from the window of view with time constants in the range of 8 to 14 min, which corresponds to droplet nuclei of ca. 4 µm diameter, or 12- to 21-µm droplets prior to dehydration. These observations confirm that there is a substantial probability that normal speaking causes airborne virus transmission in confined environments."*
Buonanno, G.; Stabilea, L.; Morawska, L. (2020) **Estimation of airborne viral emission: Quanta emission rate of SARS-CoV-2 for infection risk assessment.** *Environment International*, Volume 141 (2020) 105794. Published: 11 May, 2020. https://www.sciencedirect.com/science/article/pii/S0160412020312800	*"The results showed that high quanta emission rates (> 100 quanta h−1) can be reached by an asymptomatic infectious SARS-CoV-2 subject performing vocalization during light activities (i.e. walking slowly) whereas a symptomatic SARS-CoV-2 subject in resting conditions mostly has a low quanta emission rate (< 1 quantum h−1)."* *"…a quantum is defined as the dose of airborne droplet nuclei required to cause infection in 63% of susceptible persons…"* *"The findings in terms of quanta emission rates were then adopted in infection risk models to demonstrate its application by evaluating the number of people infected by an asymptomatic SARS-CoV-2 subject in Italian indoor microenvironments before and after the introduction of virus containment measures. The results obtained from the simulations clearly highlight that a key role is played by proper ventilation in containment of the virus in indoor environments."*
Somsen, G.A. *et al* (2020) Small droplet aerosols in poorly ventilated spaces and SARS-CoV-2 transmission. *Lancet Respir Med*, 2020. Published: 27 May, 2020. https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30245-9/fulltext	*"To better understand the spreading of respiratory droplets and possible preventive measures, we analysed droplet production due to coughs and speech by measuring the droplet size distribution, travel distance and velocity, and the airborne time in relation to the level of air ventilation."* *"In a cough from a healthy volunteer, we found two distinct types of drops, large droplets (100–1000 µm in diameter) and small droplets (1–10 µm), with the small droplets being much more prevalent. During speech, only the small droplets were found."*

Appendix: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7255254/bin/mmc1.pdf	*"… the small droplets of typical radius of 5 μm will take 9 min to reach the ground when produced at a height of 160 cm (ie, average speaking or coughing height). These small droplets are of specific interest because they have been associated with aerosol transmission of the SARS-CoV-2."* *"We repeated this experiment in three rooms with different levels of ventilation: no ventilation, mechanical ventilation only, and mechanical ventilation supported by the opening of an entrance door and a small window. In the best ventilated room, after 30 s the number of droplets had halved, whereas with no ventilation this took about 5 min, in agreement with the air drag calculation that shows that 5 μm drops from the average cough or speech height take 9 min to reach the ground. In a poorly ventilated room, the number of droplets was halved in 1·4 min."* *"Transmission by aerosols of the small droplets studied here can only be prevented by use of high-performance face masks; a conventional surgical mask only stops 30% of the small aerosol droplets studied here for inhaled breath; for exhaled breath the efficacy is much better."* *"This study shows that better ventilation of spaces substantially reduces the airborne time of respiratory droplets. This finding is relevant because typically poorly ventilated and populated spaces, like public transport and nursing homes, have been reported as sites of viral transmission despite preventive physical distancing."*
Santarpia, J.L. *et al* (2020) **Aerosol and Surface Transmission Potential of SARS-CoV-2.** *medRxiv*, 2020.03.23.20039446. Published: 3 June, 2020. https://www.medrxiv.org/content/10.1101/2020.03.23.20039446v3	*"During the initial isolation of 13 individuals with COVID-19 at the University of Nebraska Medical Center, we collected air and surface samples to examine viral shedding from isolated individuals. We detected viral contamination among all samples, indicating that SARS-CoV-2 may spread through both direct (droplet and person-to-person) as well as indirect mechanisms (contaminated objects and airborne transmission). Taken together, these finding support the use of airborne isolation precautions when caring for COVID-19 patients."* *"We found 63.2% of in-room air samples to be positive by RT-PCR."*
Fears, A.C. *et al* (2020) **Comparative dynamic aerosol efficiencies of three emergent coronaviruses and the unusual persistence of SARS-CoV-2 in aerosol suspensions.** *medRxiv*, 2020.04.13.20063784. Published: 18 April, 2020.	*"The comparison of short-term aerosol efficiencies of three emergent coronaviruses showed SARS-CoV-2 is on par with or exceeding the efficiency estimates of SARS-CoV and MERS-CoV."* *"Collectively, this preliminary dataset on the aerosol efficiency and persistence of SARSCoV-2 suggest that this virus is remarkably resilient in aerosol form, even when*

https://www.medrxiv.org/content/10.1101/2020.04.13.20063784v1	*aged for over 12 hours, and reinforces the conclusions reached in earlier studies of aerosol fitness by others."*
Fears, A.C. *et al* (2020) **Persistence of severe acute respiratory syndrome coronavirus 2 in aerosol suspensions.** *Emerg Infect Dis*. 2020. Published: 22 June, 2020. https://doi.org/10.3201/eid2609.201806	*"We aerosolized severe acute respiratory syndrome coronavirus 2 and determined that its dynamic aerosol efficiency surpassed those of severe acute respiratory syndrome coronavirus and Middle East respiratory syndrome. Although we performed experiment only once across several laboratories, our findings suggest retained infectivity and virion integrity for up to 16 hours in respirable-sized aerosols."*

C. WHO & CDC Guidance on masks

WHO Guidance: WHO (2020) ***Advice on the use of masks in the context of COVID-19. Interim guidance.*** WHO, Geneva, Switzerland. Published: 5 June, 2020. https://www.who.int/publications/i/item/advice-on-the-use-of-masks-in-the-community-during-home-care-and-in-healthcare-settings-in-the-context-of-the-novel-coronavirus-(2019-ncov)-outbreak	*"…taking into account the available studies evaluating pre- and asymptomatic transmission, a growing compendium of observational evidence on the use of masks by the general public in several countries, individual values and preferences, as well as the difficulty of physical distancing in many contexts, WHO has updated its guidance to advise that to prevent COVID-19 transmission effectively in areas of community transmission, governments should encourage the general public to wear masks in specific situations and settings as part of a comprehensive approach to suppress SARS-CoV-2 transmission."* *"A minimum of three layers is required for non-medical masks, depending on the fabric used…. The ideal combination of material for non-medical masks should include three layers as follows:* *1) an innermost layer of a hydrophilic material (e.g. cotton or cotton blends);* *2) an outermost layer made of hydrophobic material (e.g., polypropylene, polyester, or their blends) which may limit external contamination from penetration through to the wearer's nose and mouth;* *3) a middle hydrophobic layer of synthetic non-woven material such as polyproplylene or a cotton layer which may enhance filtration or retain droplets."*
CDC Guidance: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/cloth-face-cover.html	*"CDC continues to study the spread and effects of the novel coronavirus across the United States. We now know from recent studies that a significant portion of individuals with coronavirus lack symptoms ("asymptomatic") and that even those who eventually develop symptoms ("pre-symptomatic") can transmit the virus to others before showing symptoms. This means that the virus can spread between people interacting in close proximity—for*

	example, speaking, coughing, or sneezing—even if those people are not exhibiting symptoms. In light of this new evidence, CDC recommends wearing cloth face coverings in public settings where other social distancing measures are difficult to maintain (e.g., grocery stores and pharmacies) ***especially*** *in areas of significant community-based transmission."*