

Quantifying transmission risk of SARS-CoV-2 in different situations

T. Greenhalgh¹, Zhe Peng², Jose L. Jimenez², W Bahnfleth³, S Dancer^{4,5}, L. Bourouiba⁶ (on behalf of 22 authors of the original paper)

1. Nuffield Department of Primary Care Health Sciences, University of Oxford, Oxford OX2 6GG, UK.
2. Dept. of Chemistry and Cooperative Institute for Research in Environmental Sciences; University of Colorado; Boulder, CO 80309, USA
3. Dept. of Architectural Engineering, The Pennsylvania State University, University Park, Pennsylvania 16802, United States
4. Dept. of Microbiology, NHS Lanarkshire, Glasgow, Scotland G75 8RG, U.K.
5. School of Applied Sciences, Edinburgh Napier University, Scotland EH11 4BN, U.K.
6. The Fluid Dynamics of Disease Transmission Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

SARS-CoV-2 is transmitted mainly through short- and long-range airborne transmission.^{1,2} Omicron, now dominant in many countries, shows faster transmission and greater vaccine escape than previous variants.³ Further measures are needed to contain transmission.

In August 2020, we argued that “Rigid safe distancing rules are an oversimplification based on outdated science”.⁴ We produced risk charts for SARS-CoV-2 transmission incorporating multiple variables: indoors versus outdoors (and, for the former, level of ventilation), room occupancy (low or high), time spent together (short or long), vocalisation (silent, speaking, shouting or singing), and masking (yes or no).

While these Covid risk charts have been translated into over 30 languages,⁵ rapid responses to the article criticised the authors for providing relative, rather than absolute, estimates of risk levels. We knew, for example, that speaking and singing would transmit more airborne particles than remaining silent – but how much more, and over what length of time?

We have now developed a mathematical model to quantify further these relative risks with updated data.⁶ Our model, which assumes a single enclosed space in which viral-containing aerosols exhaled by a single infected human become rapidly mixed, is based on models developed for infectious disease spread through the air (e.g. measles⁷). It takes account of the disease-specific emission rate of viral-carrying particles (quanta), the increase in emission of viral particles with vocalization and exercise, room volume, room occupancy (assumed to be stable and continuous), rate of particle removal either naturally (e.g. opening windows) or mechanically (e.g. replacement with outdoor air, filtration), and the efficiency with which virus-carrying particles penetrate masks.

Details of these calculations, which are consistent with the observed variation in attack rates across twelve widely-studied super-spreader events for Covid-19, and were also applied to other outbreaks of tuberculosis, influenza and measles, are published in the technical paper.⁶ One of the attack rate charts from the resultant model is reproduced in Figure 1, with an interactive risk calculator made available online.⁸

The quantitative findings from the modelling study strongly affirm the validity of the low-, medium- and high-risk social situations set out in the original BMJ paper from August 2020.⁴ We have added quantitative risks of transmission to all the original scenarios, including additional data on the risks of exercise whereby heavy breathing greatly increases viral emission from infected individuals. The model, however, does not account for all variables, notably overlapping breathing zones between individuals and known airflow heterogeneity indoors (see technical paper for details⁶).

As transmission escalates despite vaccination, fuelled by shedding from asymptomatic carriers,⁹ we should note the perils of mixing unmasked in crowded and under-ventilated indoor spaces, especially when singing or exercising. When prevalence decreases after the current wave, more activities become low risk.

Type and level of group activity	Low occupancy			High occupancy		
	Outdoor and well ventilated	Indoor and well ventilated	Poorly ventilated	Outdoor and well ventilated	Indoor and well ventilated	Poorly ventilated
Wear face coverings, contact for short time						
Silent	<0.001%	0.020%	0.052%	0.001%	0.074%	0.19%
Speaking	0.001%	0.097%	0.25%	0.005%	0.37%	0.96%
Shouting, singing	0.008%	0.57%	1.4%	0.032%	2.1%	5.2%
Heavy exercise	0.020%	1.3%	2.9%	0.074%	4.7%	11%
Wear face coverings, contact for prolonged time						
Silent	0.003%	0.23%	1.2%	0.011%	0.86%	4.4%
Speaking	0.014%	1.1%	4.5%	0.053%	4.0%	16%
Shouting, singing	0.084%	4.7%	8.5%	0.32%	17%	29%
Heavy exercise	0.19%	7.3%	8.6%	0.73%	25%	29%
No face coverings, contact for short time						
Silent	0.001%	0.056%	0.15%	0.003%	0.21%	0.55%
Speaking	0.004%	0.27%	0.71%	0.015%	1.0%	2.6%
Shouting, singing	0.024%	1.5%	3.4%	0.091%	5.6%	12%
Heavy exercise	0.056%	3.1%	6.0%	0.21%	11%	21%
No face coverings, contact for prolonged time						
Silent	0.008%	0.63%	2.9%	0.030%	2.4%	11%
Speaking	0.040%	2.7%	7.5%	0.15%	9.9%	26%
Shouting, singing	0.24%	7.7%	8.6%	0.89%	26%	29%
Heavy exercise	0.54%	8.6%	8.6%	2.0%	29%	29%

Figure 1: Relative risk in terms of attack rate (%) estimation of transmission of SARS-CoV-2 in different social mixing scenarios and activities, shown for the Omicron variant and for a prevalence in the population of 1%.

Reproduced and adapted with permission from Peng et al⁹ (see Table S3 of Peng et al for the specifications of these scenarios). The table can be adapted to other circumstances in the online calculator at <http://tinyurl.com/COVID-Tables>.⁸ Table was updated on 27-Jan-2021.

1. Greenhalgh T, Jimenez JL, Prather KA, et al. Ten scientific reasons in support of airborne transmission of SARS-CoV-2. *The Lancet* 2021;397(10285):1603-05.
2. World Health Organisation. Coronavirus disease (COVID-19): How is it transmitted? (Updated 21st December 2021). Geneva: WHO. Accessed 27th December 2021 at <https://www.who.int/news-room/questions-and-answers/item/coronavirus-disease-covid-19-how-is-it-transmitted> 2021.
3. Chen J, Wang R, Gilby NB, et al. Omicron (B. 1.1. 529): Infectivity, vaccine breakthrough, and antibody resistance. *ArXiv* 2021
4. Jones NR, Qureshi ZU, Temple RJ, et al. Two metres or one: what is the evidence for physical distancing in covid-19? *bmj* 2020;370
5. CovidStraightTalk. The #COVIDRISKCHART in 34 languages: CovidStraightTalk.org 2020.
6. Peng Z, Rojas ALP, Kropff E, et al. Practical Indicators for Risk of Airborne Transmission in Shared Indoor Environments and Their Application to COVID-19 Outbreaks. *Environmental Science & Technology* 2022;56(2):1125-37.
7. Riley E, Murphy G, Riley R. Airborne spread of measles in a suburban elementary school. *American journal of epidemiology* 1978;107(5):421-32.
8. Jimenez JL, Peng Z. COVID-19 aerosol transmission estimator. Colorado: University of Colorado. Accessed 27th December 2021 at <https://tinyurl.com/covid-estimator> 2021.
9. Johansson MA, Quandelacy TM, Kada S, et al. SARS-CoV-2 Transmission From People Without COVID-19 Symptoms. *JAMA network open* 2021;4(1):e2035057-e57.