Alternative COVID-19 mitigation measures in school classrooms: analysis using an agent-based model of SARS-CoV-2 transmission

M. J. Woodhouse, W. P. Aspinall, R. S. J. Sparks, E. Brooks-Pollock, C. Relton

Supplementary Material Appendix A1: The role of airborne transmission in close contact transmission of SARS-CoV-2

One of the emerging ideas on the spread of SARS-CoV-2 is that it occurs by airborne transmission of aerosols carrying the virus [20]. This concept has gained currency as evidence emerges for transmission in settings which require long distance transport of fine aerosols, away from an infected source, as recently summarized in [1]. The specific principles and issues related to airborne transmission in classrooms and factors related to ventilation in schools have been reviewed by Ding et al. (2022) [41]. Transmission and risk models have been developed [e.g., 38, 42, 43] which frame transmission risk in terms of long-range dispersal of aerosols within closed and open spaces. The transmission risk is a function of many parameters but, at its basic level, is controlled by the balance between recharge of a closed space with aerosols from infected persons and their removal by fresh air or ventilation. Exposure risk increases as viral concentration within the aerosols increases and is also as a function of exposure time. Aerosol size is also likely to play a role as size affects buoyancy and persistence in suspension.

In contrast, many epidemiological models, including the agent-based model in our paper, identify close contact with an infected person as the main circumstance for viral transmission to a susceptible person. This justifies social distancing as a primary approach to mitigation. Long-range and short-range exposure models to airborne aerosols are not mutually exclusive. Indeed, both kinds of process will occur concurrently in many settings [20, 41]. The question then is in what circumstances does one or the other become dominant?

Here we consider the case that short range airborne exposure is likely to be dominant in many classroom settings, supporting the development and validity of agent-based close contact models. The main concept is that various kinds of exhalation (e.g., normal breathing, talking, singing, laughing, coughing and sneezing) lead to high concentrations of virus in airborne aerosol in the immediate vicinity of an infected person [44]. Thus, the risk of being infected when close to or face-to-face with a person is greatly increased compared to the background exposure due to long range dispersal. Exhalations from an infected person create virus-laden jet plumes that involve turbulent entrainment of air, so the aerosol becomes diluted as the plume disperses. Relevant research has been recently reviewed in Burridge et al. [45]. Abkarian et al. (2020) [44] and Chen et al. (2020) [46] provide quantification of typical dilution rates as a function of distance in exhalations. As examples, the concentration of aerosols in a turbulent jet produced by speech reduces to 6% at 1m and 3% at 2m from its initial value [44]. Concentrations of fine aerosols significantly above background are calculated at up to 0.3 m for speech (counting) and up to 1 m for coughing [46]. Substantial distances, greater than typical classroom sizes, are required for concentrations in the respiratory jet to reach background levels [38]. Because proximity (~ 1 m) to an infected person is now a recognised major risk factor, these results, and the illustration below, support our model choice of close contact as the predominant mechanism in a school classroom.

In order to appraise the relative risk of infection to pupils in the room, away from close contacts, we can compare the background concentration of infected aerosol with the local concentration close to an infected person. Let us take 6 litres per minute of air inhaled as typical of both an adult female and a primary age child (with adult males 50% higher) [47] and assume the concentration of virus-bearing aerosol of an infected child is some unknown value C. Taking a classroom of 8×6 m as the minimum in UK Primary schools with height 3 m we have a volume of 144,000 litres. We now need a suitable time scale and choose 3 hours, noting that this is the duration of a school half day and that the half-life of the virus is 1.1 hours [48]. Thus, the room cannot have a concentration more than $0.0075C$. However, the concentration will be very much less if there is ventilation. According to [41] a classroom of 30 children should have a room ventilation rate of at least 120 litres per minute, meaning that it would take only 20 minutes to replace the air in a classroom. Here the background concentration of infected aerosol would be approximately 10^{-3} C. Thus, concentrations of virus in aerosols, and therefore risk of infection, can be tens to hundreds of times greater than background within a metre of an infected person. We conclude that, in most circumstances, close contacts will dominate transmission in a primary school classroom, and so justifies our choice of model. We acknowledge that risk from long range airborne transmission could become much more significant in situations of poorly ventilated classrooms and with multiple infected pupils during an outbreak.

References

(numbering continued from main document)

1. Greenhalgh T, Jimenez JL, Prather KA, Tufekci Z, Fisman D, Schooley R. 2021 Ten scientific reasons in support of airborne transmission of SARS-CoV-2. *The Lancet*. **397**, 1603-1605. (doi:10.1016/S0140-6736(21)00869-2)

20. Leung NHL. 2021 Transmissibility and transmission of respiratory viruses. *Nat. Rev. Microbiol.* **19**, 528-545. (doi:10.1038/s41579-021-00535-6)

38. Bazant MZ, Bush JWM. 2021 A guideline to limit indoor airborne transmission of COVID-19. *Proc. Natl Acad. Sci. USA* **118**, e2018995118. (doi:10.1073/pnas.2018995118)

41. Ding E, Zhang D, Bluyssen PM. 2022 Ventilation regimes of school classrooms against airborne transmission of infectious respiratory droplets: a review. *Build. Environ.* **207**, 108484. (doi:10.1016/j.buildenv.2021.108484)

42. Peng Z *et al*. 2022 Practical Indicators for Risk of Airborne Transmission in Shared Indoor Environments and Their Application to COVID-19 Outbreaks. *Environ. Sci. Technol.* **56**(2). 1125—1137. (doi:10.1021/acs.est.1c06531)

43. Burridge HC, Fan S, Jones RL, Noakes CJ, Linden PF. 2021 Predictive and retrospective modelling of airborne infection risk using monitored carbon dioxide. *Indoor Built Environ.* **0**, 1420326X211043564. (doi:10.1177/1420326x211043564)

44. Abkarian M, Mendez S, Xue N, Yang F, Stone, HA. 2020 Speech can produce jet-like transport relevant to asymptomatic spreading of virus. *Proc. Natl Acad. Sci. USA* **117**, 25237—25245. (doi:10.1073/pnas.2012156117)

45. Burridge HC *et al*. 2021 The ventilation of buildings and other mitigating measures for COVID-19: a focus on wintertime. *P. Roy. Soc. A-Math. Phy.* **477**, 20200855. (doi:10.1098/rspa.2020.0855)

46. Chen W, Zhang N, Wei J, Yen H-L, Li Y. 2020 Short-range airborne route dominates exposure of respiratory infection during close contact. *Build. Environ.* **176**, 106859. (doi:10.1016/j.buildenv.2020.106859)

47. Human respiratory tract model for radiological protection. 1994 *International Commission on Radiological Protection*. Report No.: 0146-6453 (Print) 0146-6453.

48. van Doremalen N *et al*. 2020 Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *N. Engl. J. Med.* **382**, 1564-1567. (doi:10.1056/NEJMc2004973)