Exposure to expired infectious aerosols in proximity and distance

Yuguo Li 李玉国
Department of Mechanical Engineering
/ School of Public Health
The University of Hong Kong

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To RGC, HMRF, NSFC and HKU for supporting us in studying environment control of infection since 2003.

Some general observations of COVID-19 transmission

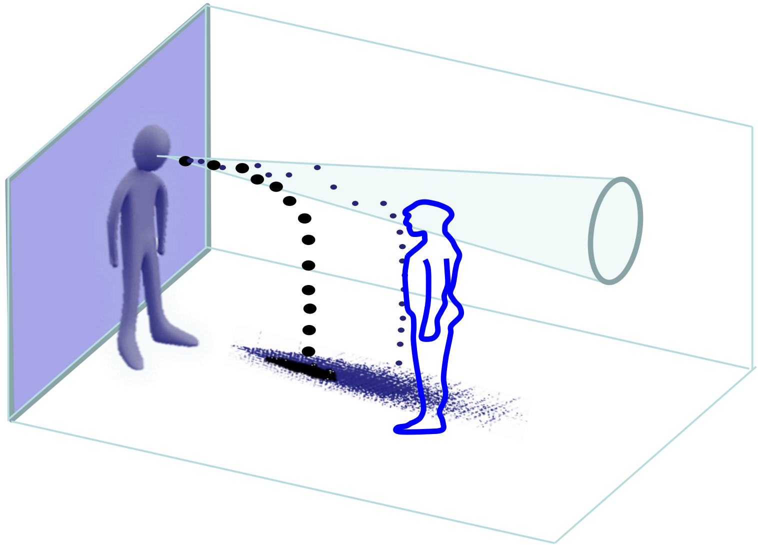
- Transmission at close range seems to dominate: having explained why social distancing worked
  Jarvis CI, et al. 2020. Quantifying the impact of physical distance measures on the transmission of COVID-19 in the UK. BMC Medicine, 18, pp.1-10.
  Dehning J, et al. Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. Science (2020).

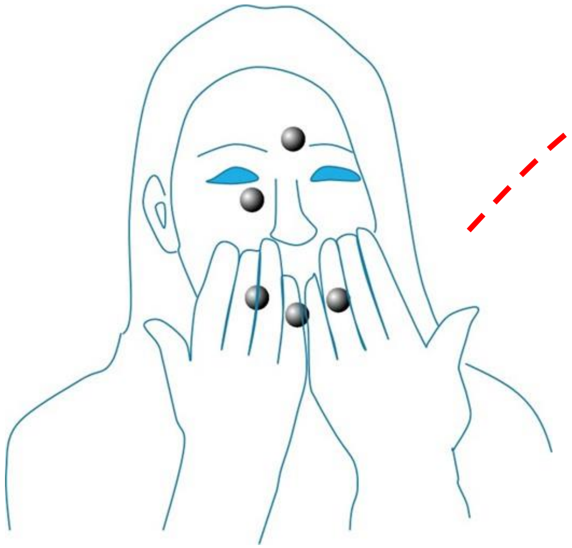
- Distant transmission reported occasionally: often leads to super spreading events

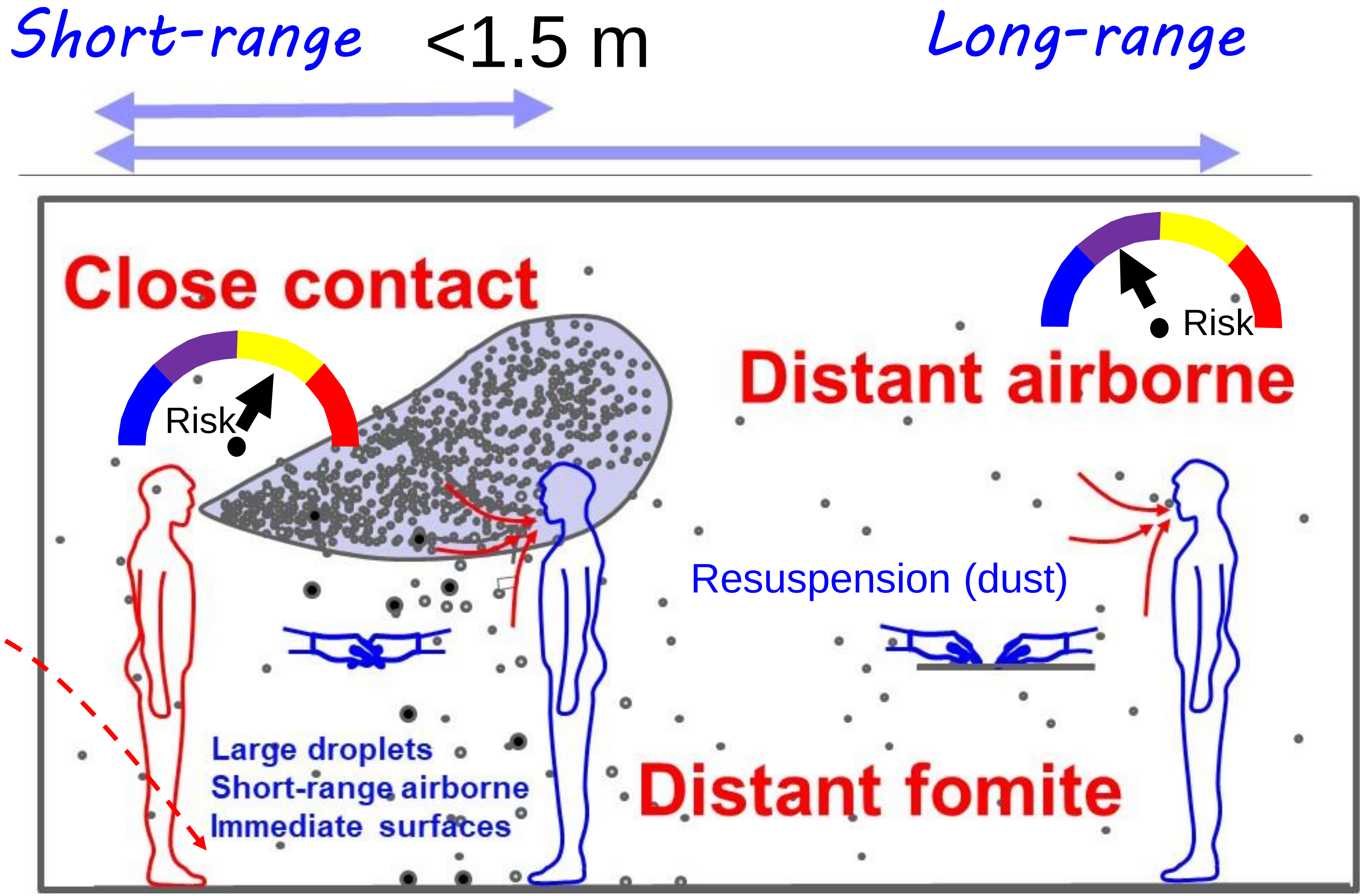
- Mass face masks have worked due to (incomplete) filtration or jet blockage. Some evidence for the infected mask wearer to stop transmission, and debate continues
  - MacIntyre CR, et al. 2020. Human coronavirus data from four clinical trials of masks and respirators. International Journal of Infectious Diseases.
  - Leung NHL.et al. 2020. Respiratory virus shedding in exhaled breath and efficacy of face masks. Nat Med, 10.1038/s41591-020-0843-2

- Most infection occurred indoors. We studied 2-3 airborne outbreaks due to insufficient ventilation (<3 L/s).
  - Qian H. et al. 2020. Indoor transmission of SARS-CoV-2. medRxiv.
  - Li et al., Probable airborne transmission of SARS-CoV-2 in a poorly ventilated restaurant. submitted for publication
  - Hang et al., Probable airborne transmission of SARS-CoV-2 on two buses due to insufficient ventilation. submitted for publication

Major transmission routes of respiratory infection







Wei J and Li Y (2016). American Journal of Infection Control, 2016 Sep 2;44(9 Suppl):S102-8.
Tang JW, Li Y, et al. (2006). Journal of Hospital Infection, 64(2), 100-14.

Traditionally dominant?

Large droplets deposit on lip/eye/nostril mucosa of a person, resulting in self-inoculation.

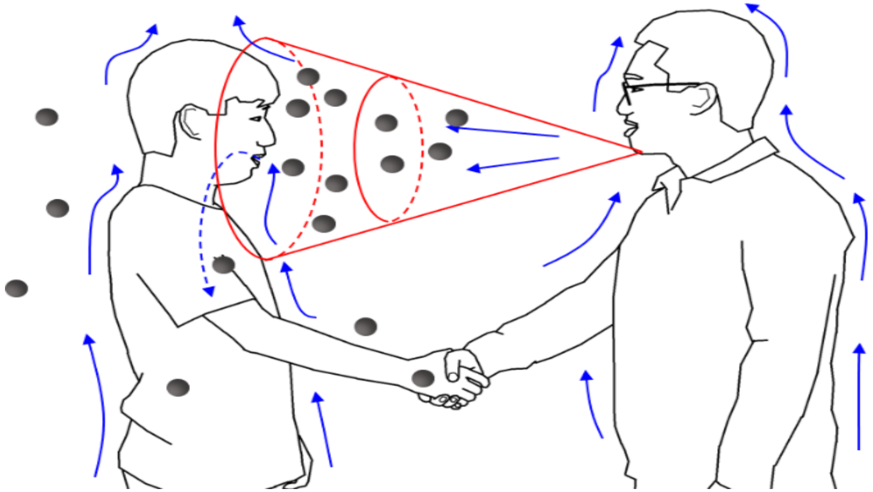
Recognized, not well studied?

?***Immediate body surfaces*** *large droplets* deposit on other areas of a person, followed by his/her hands touch and mucosa, resulting in self-inoculation.

Only recently recognized?

Short range airborne Expired fine droplets and droplet nuclei are directly inhaled.

Short-range via close contact (≤1.5 m)

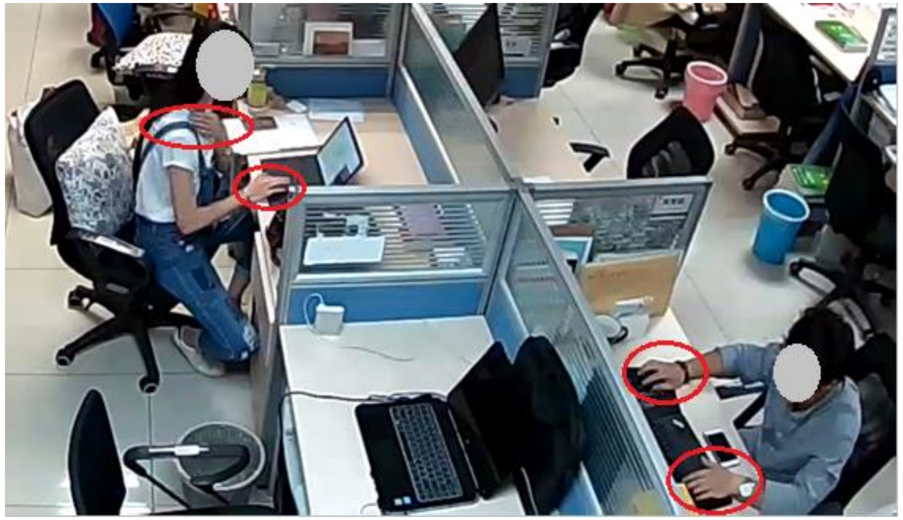


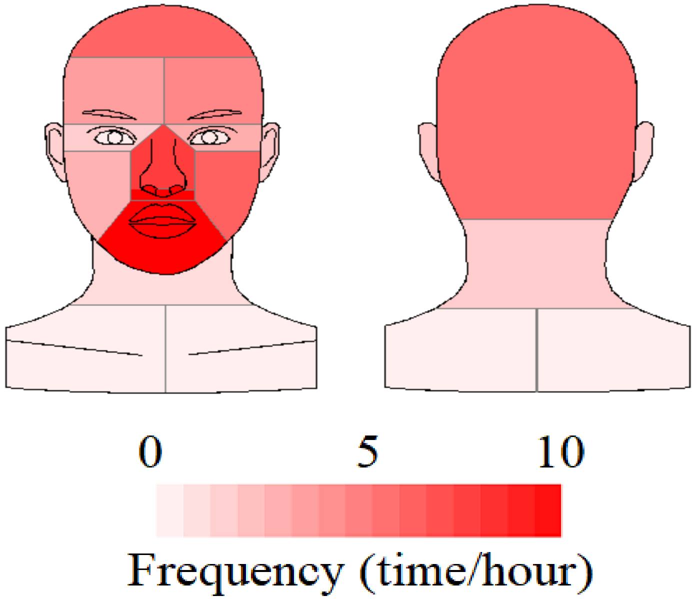
Zhang N, et al 2020. Close contact behaviour in indoor environment and transmission of respiratory infection. *Indoor Air*. doi.org/10.1111/ina.12673

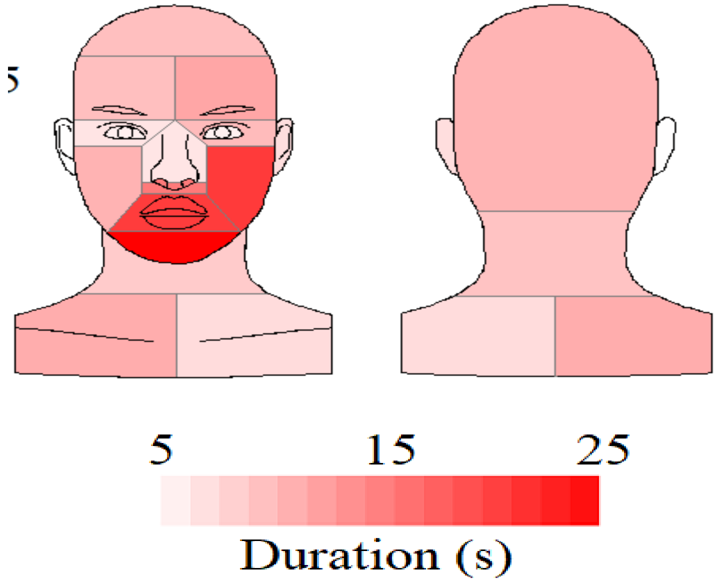
Immediate body surfaces ?

Students spend 10% time on their own hair, face, neck, and shoulders.

Non-dominant hand had more self-touches

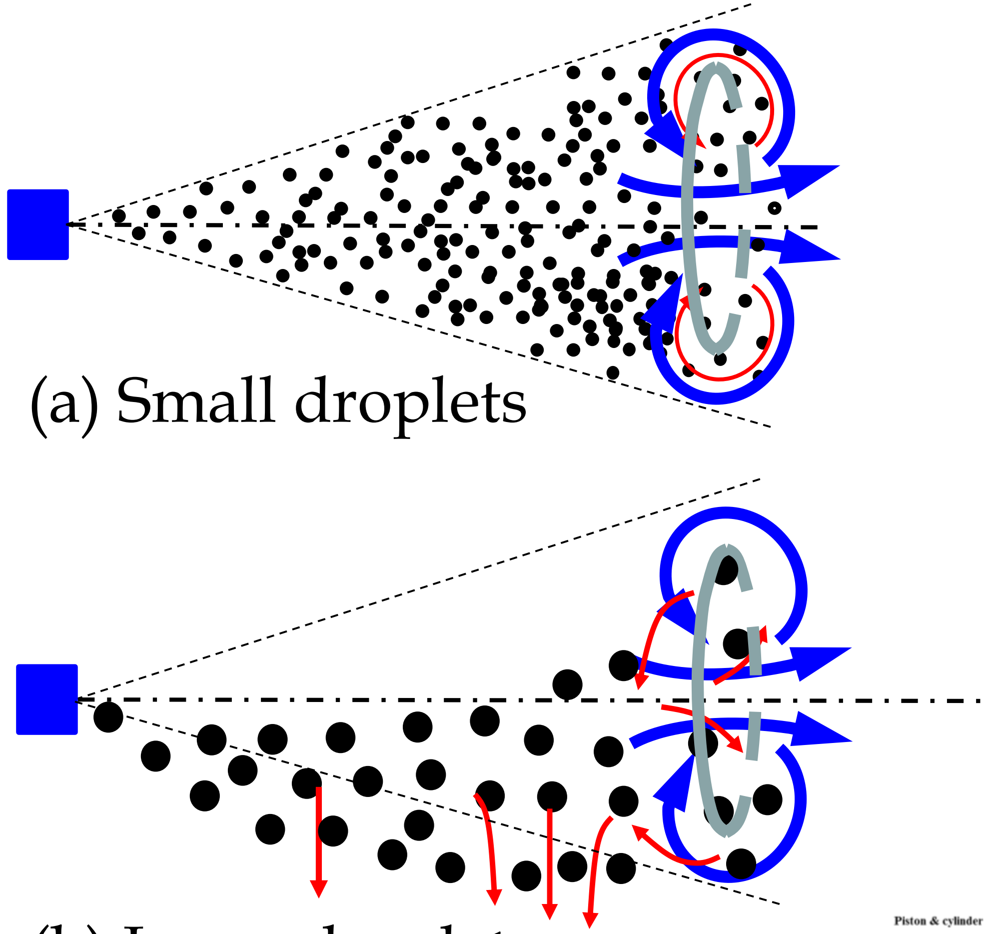






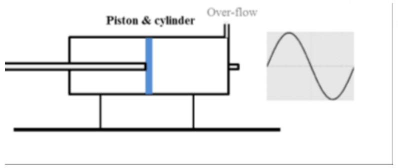
Zhang N, et al. 2018. Indoor Air, 28(6),963-972; Zhang N, et al. 2019. Indoor Air. 29, 577-590. Zhang, et al. Scientific Reports,10: 10457 (2020)

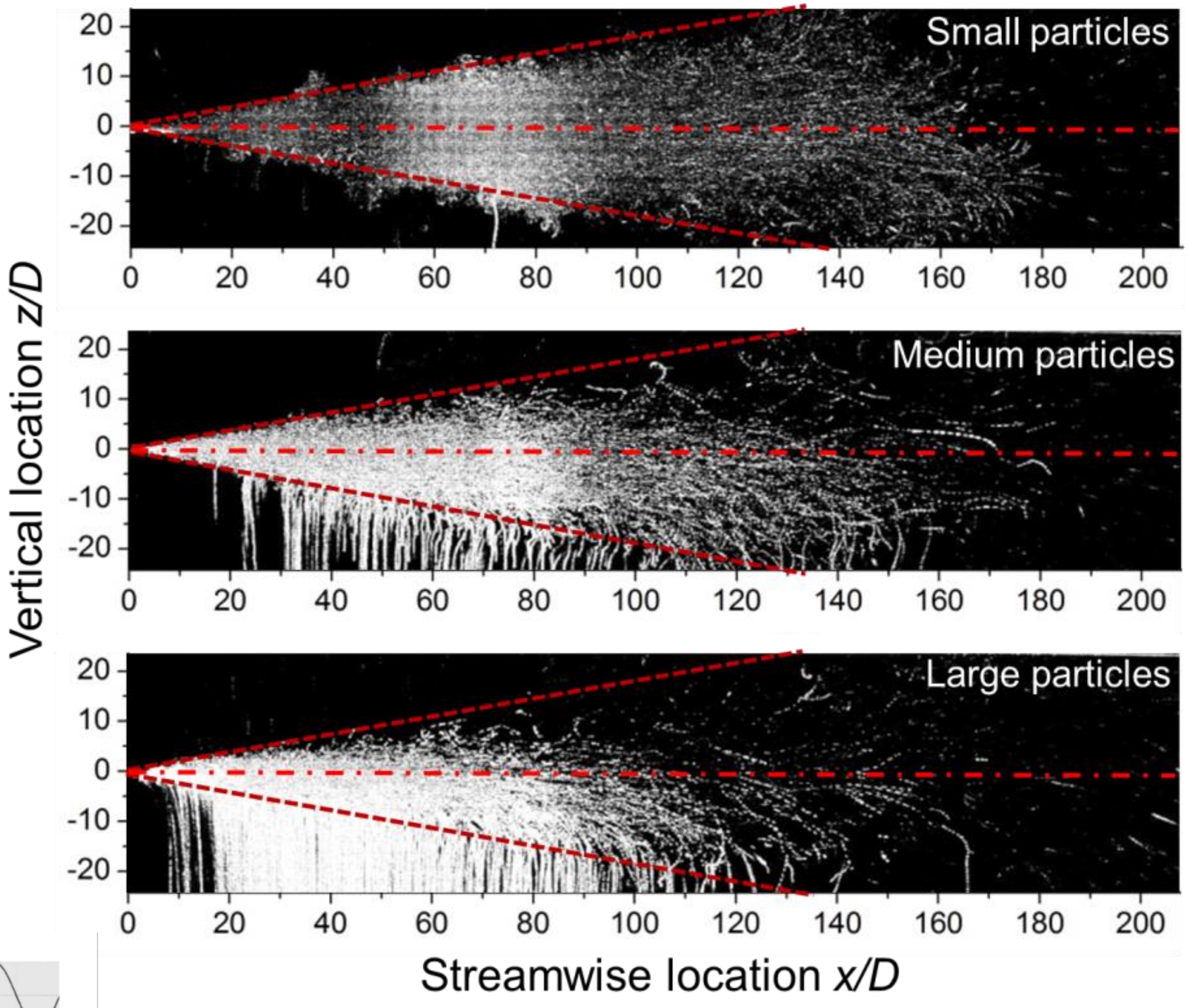
Droplet dispersion and settling in an exhaled air stream, and the leading vortex may also play a role



(a) Small droplets

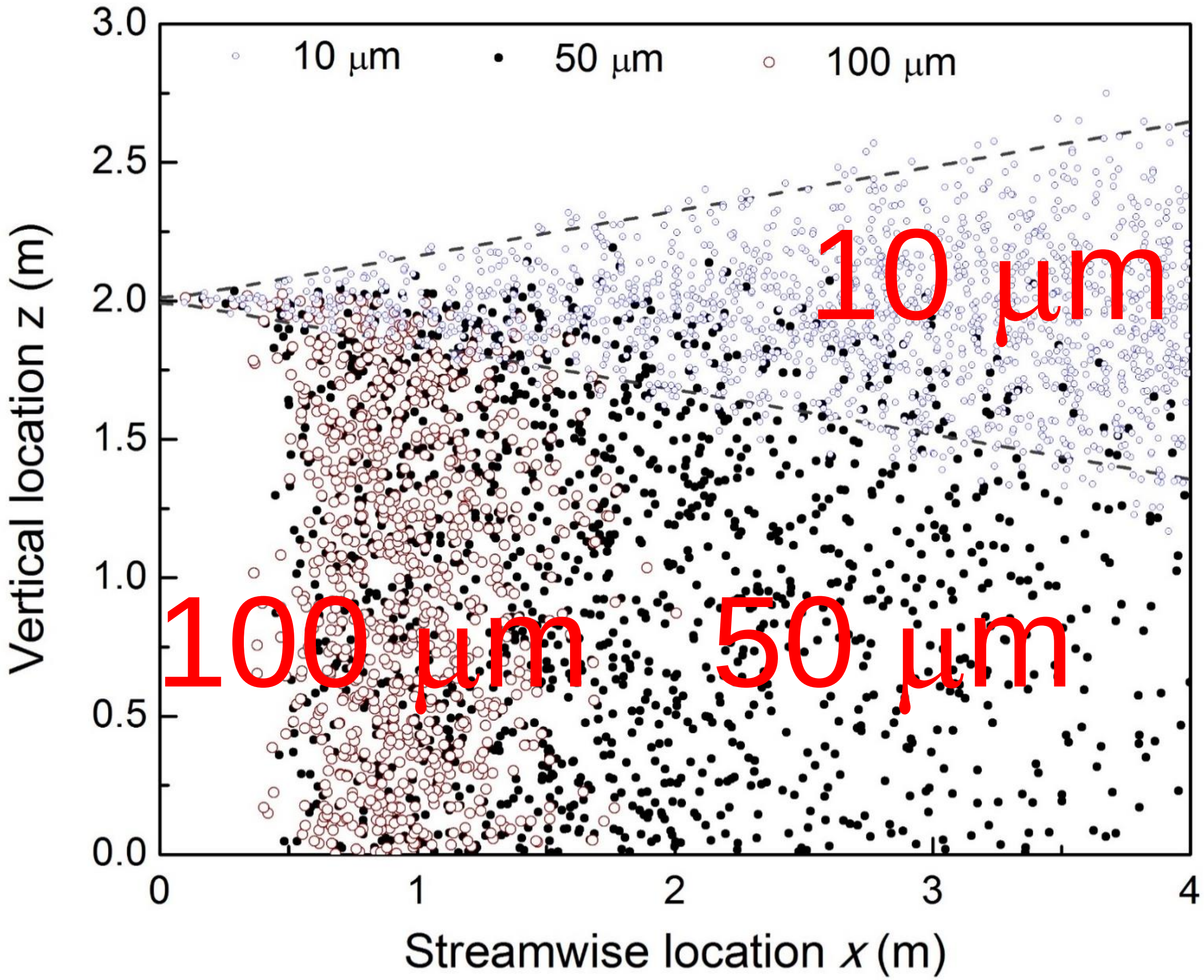
(b) Large droplets

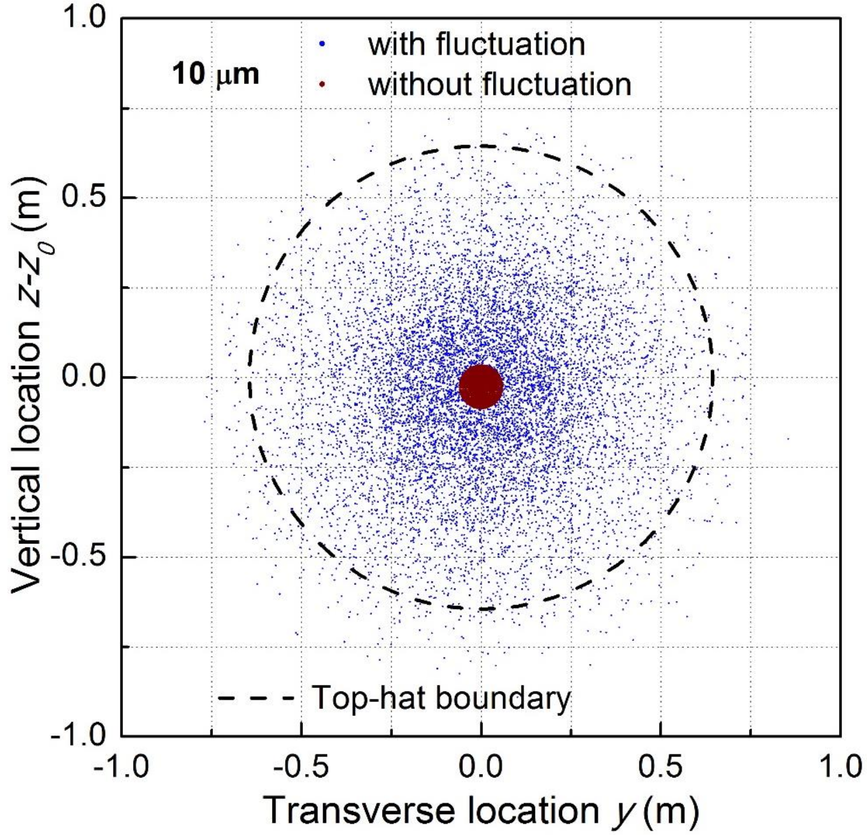




Wei J and Li Y (2017) Human cough as a two-stage jet and its role in particle transport. *PloS one*, 12(1), p.e0169235.
Wei J and Li Y (2015) Enhanced spread of expiratory droplets by turbulence in a cough jet. *Building and Environment*, 93:86-96.

Turbulence and settling

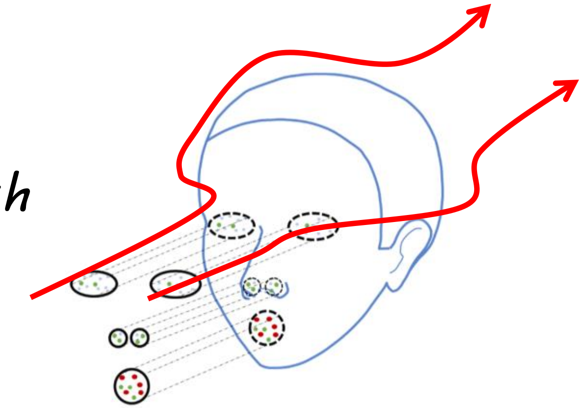


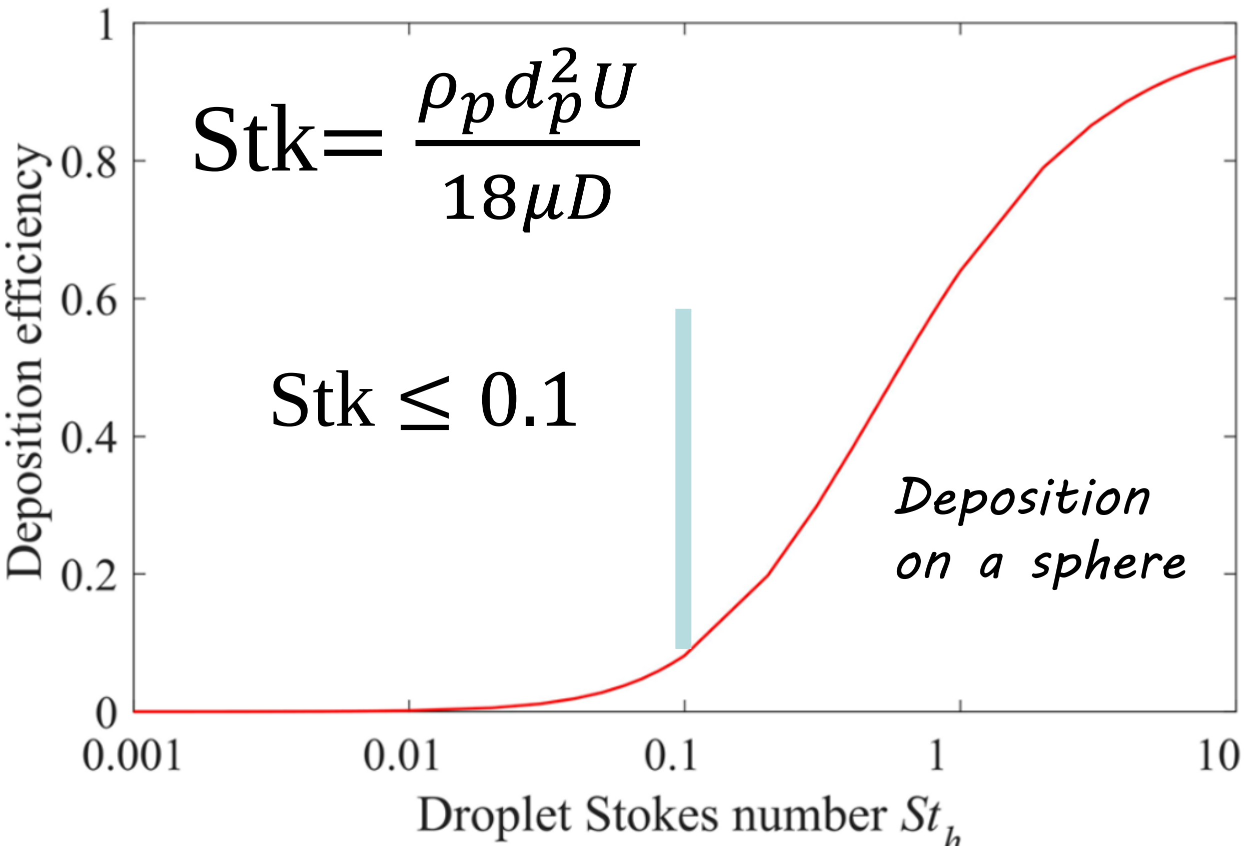


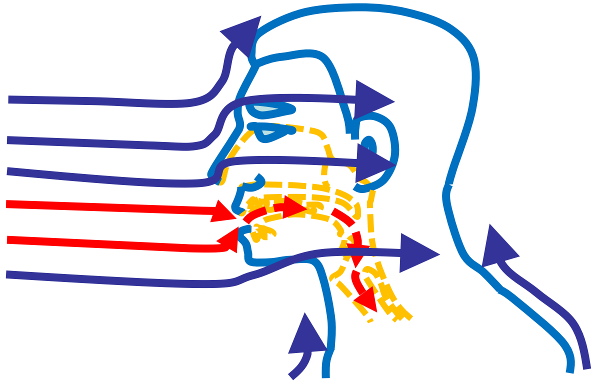
Wei J & Li Y 2015. Enhanced spread of expiratory droplets by turbulence in a cough jet. *Building and Environment*, *93*, 86-96.

Large droplet – how large? *(Droplet) spray transmission*

The threshold droplet size is 50-100 microns, not 5 or 10 microns! Only >50-100 microns can deposit on face (1m), and much less on noses, mouth and eyes. Small ones follow airflow.





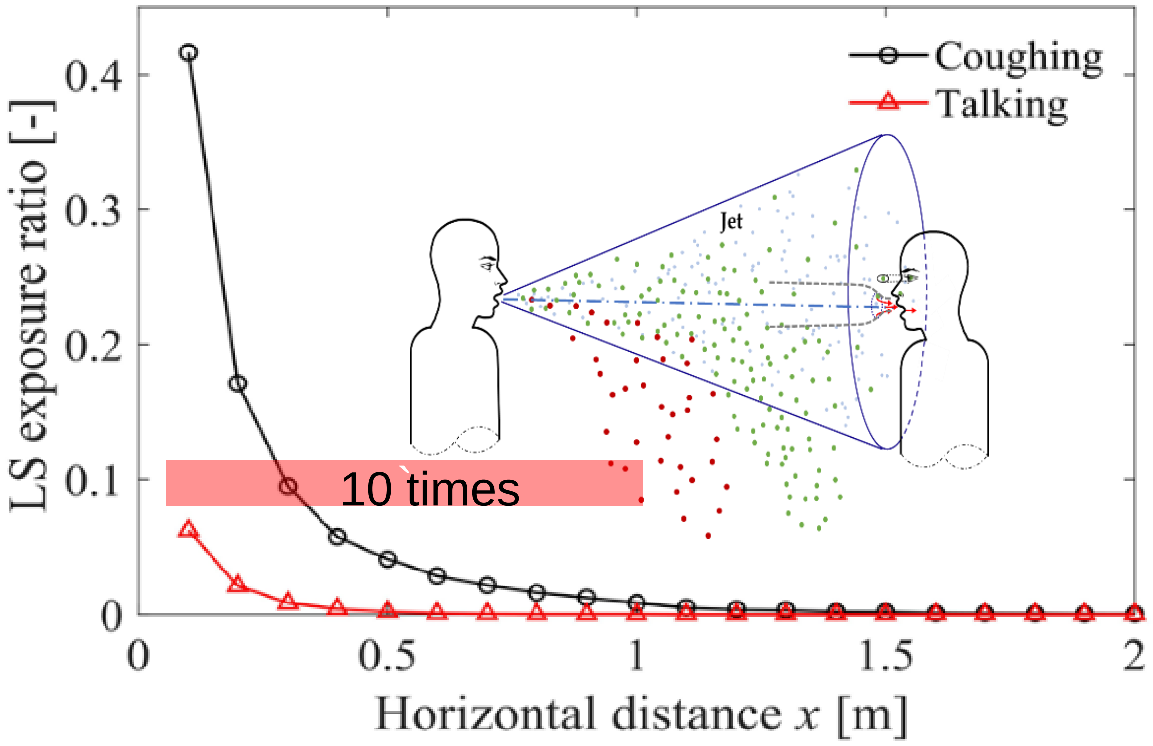


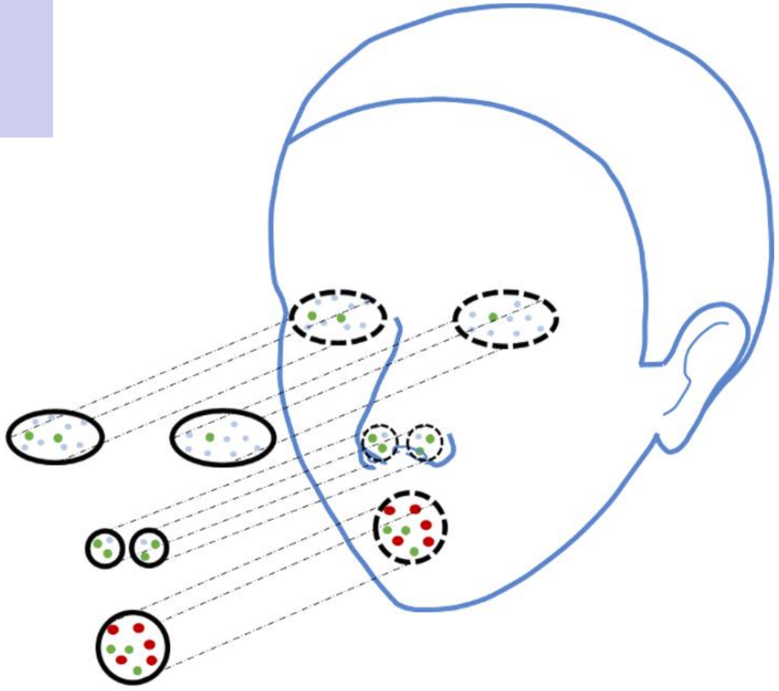
Deposition efficiency of particles in expiratory jet on a face depends on *Stokes number*

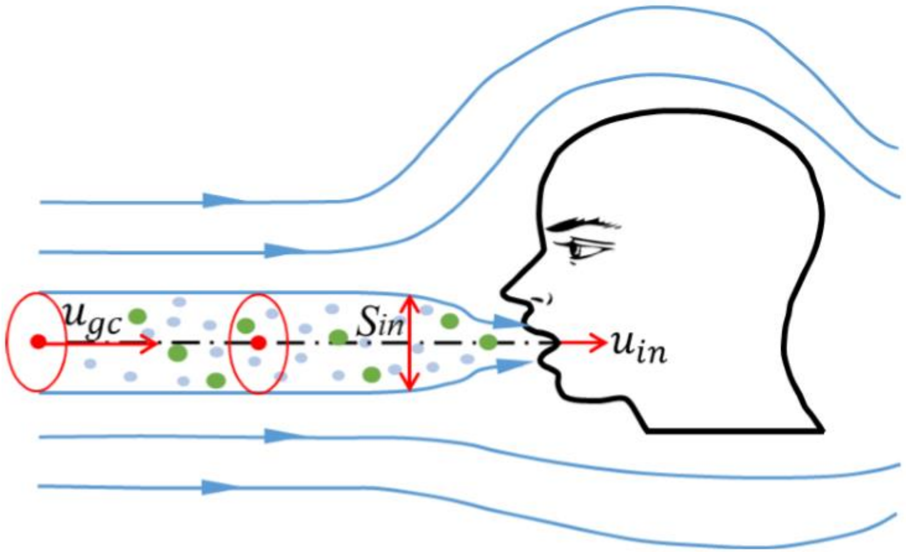
Chen et al. 2020. Building and Environment, 176, 106859

For close contact transmission, short-range airborne route is mechanistically dominant.

Exposure ratio (LS: large droplets/short-range airborne)







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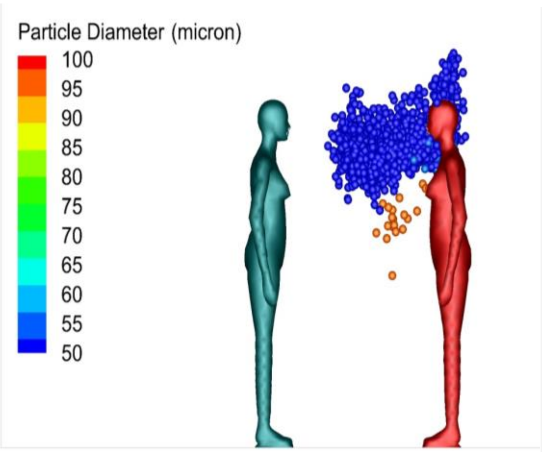
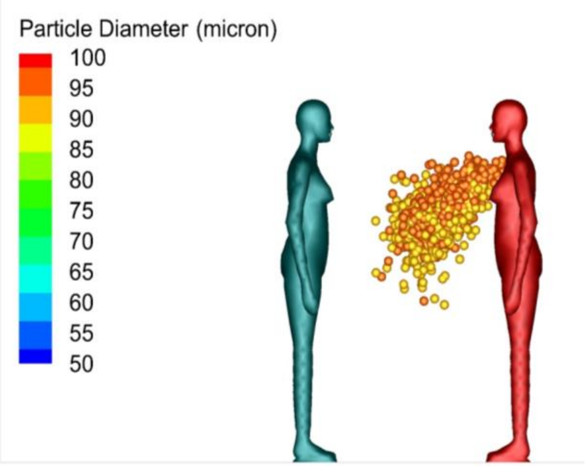
Mechanistically, short-range airborne can be 10 times more important than droplet transmission

Chen et al. 2020. Building and Environment, 176, 106859

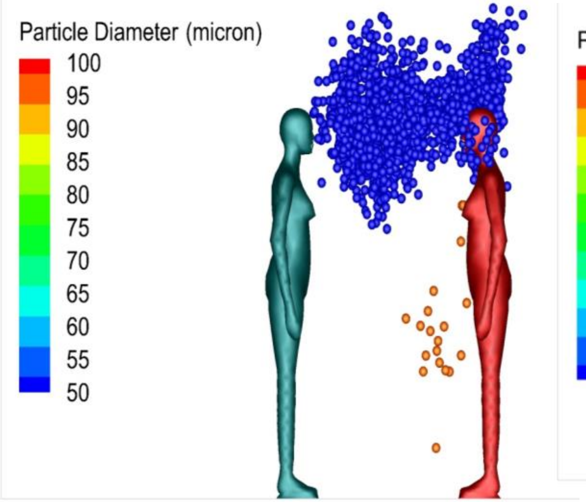
Short-range airborne route have been ignored?

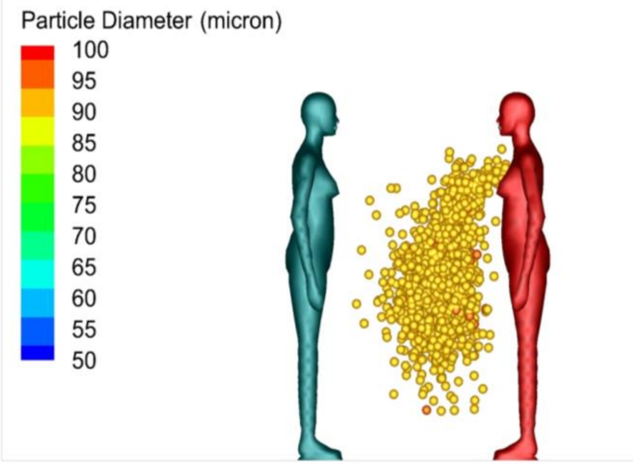


RH 35%; Time: 8 seconds



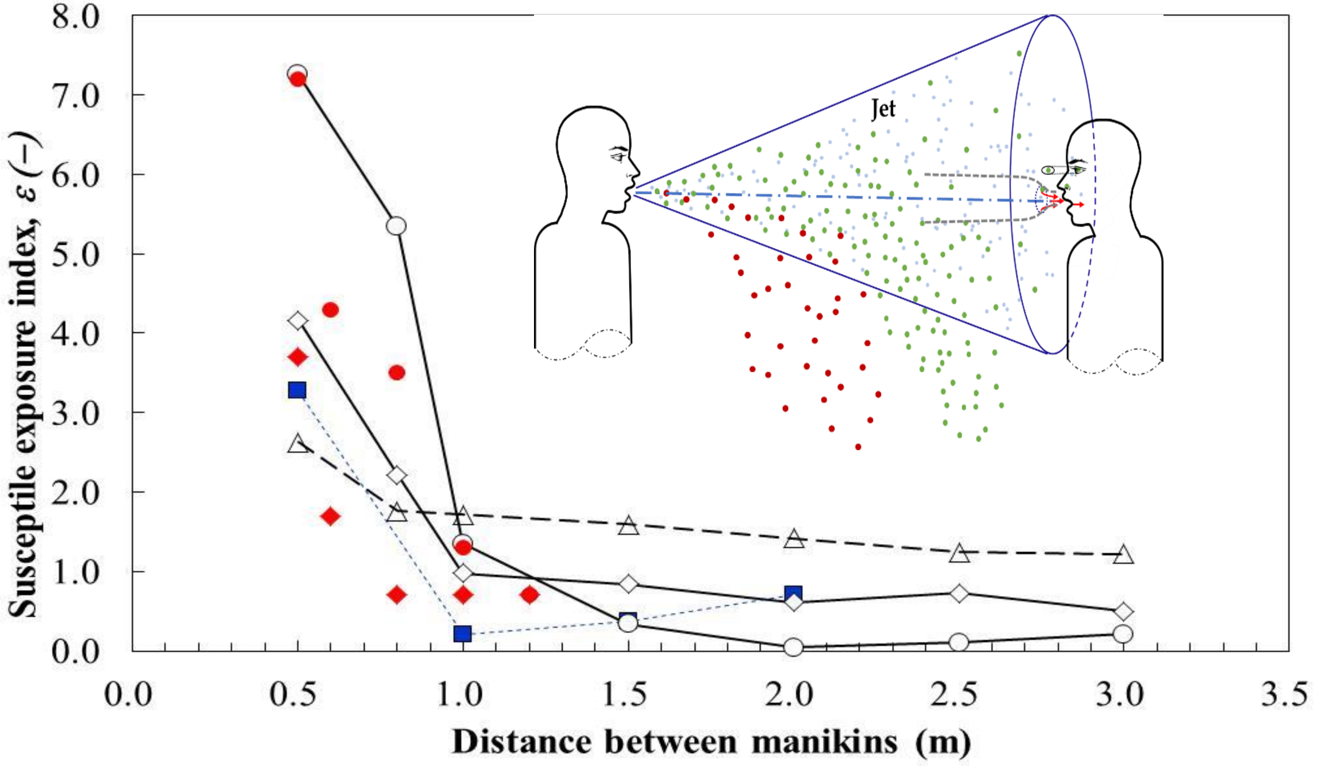
RH 95%; Time: 8 seconds





RH 35%; Time: 10 seconds

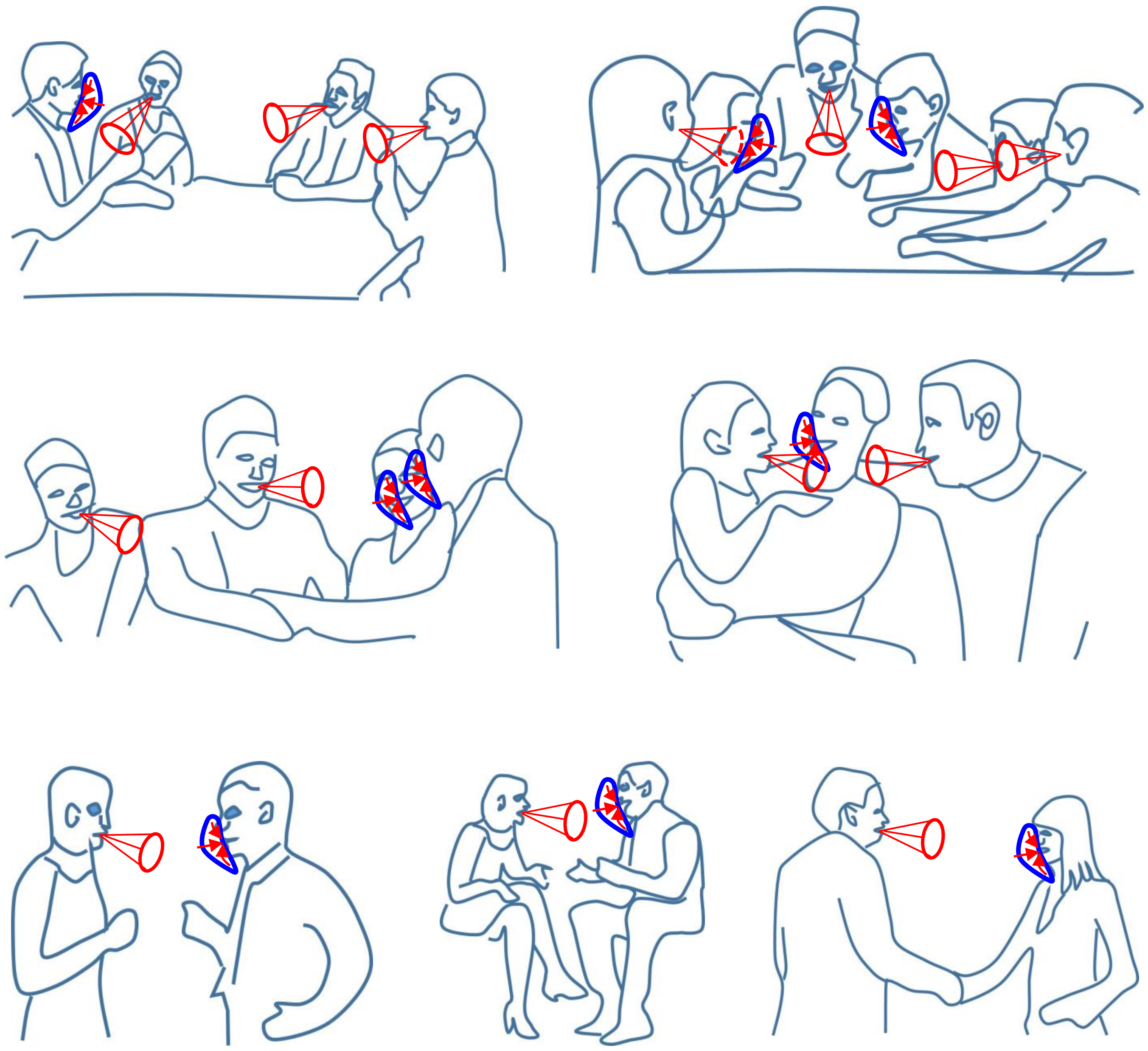
RH 95%; Time: 10 seconds

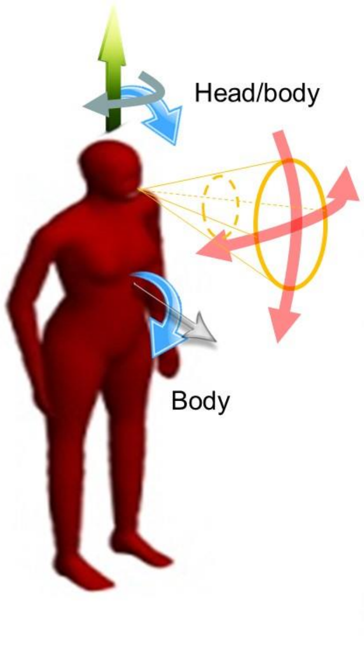


Proximity effect

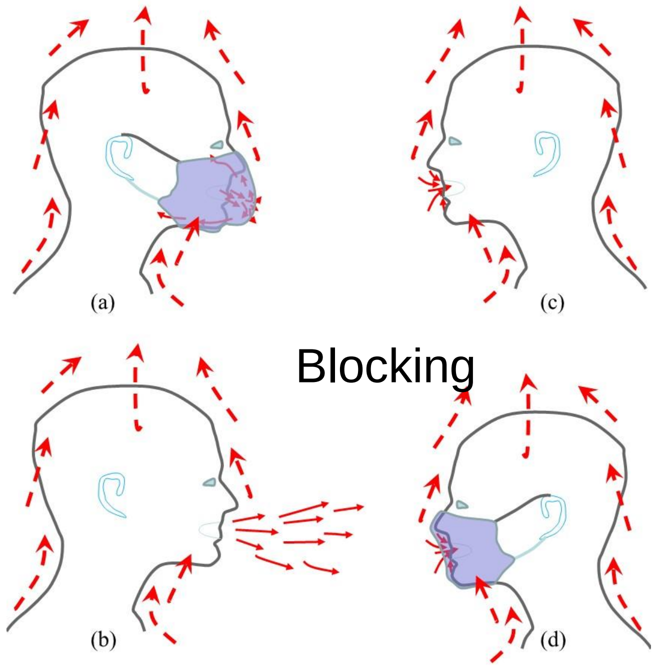
Liu L, et al 2017 Short-range airborne transmission of expiratory droplet between two people. Indoor Air, 27(2),452-462

In proximity, any two people can have partial or full respiratory connection





Head/body movement

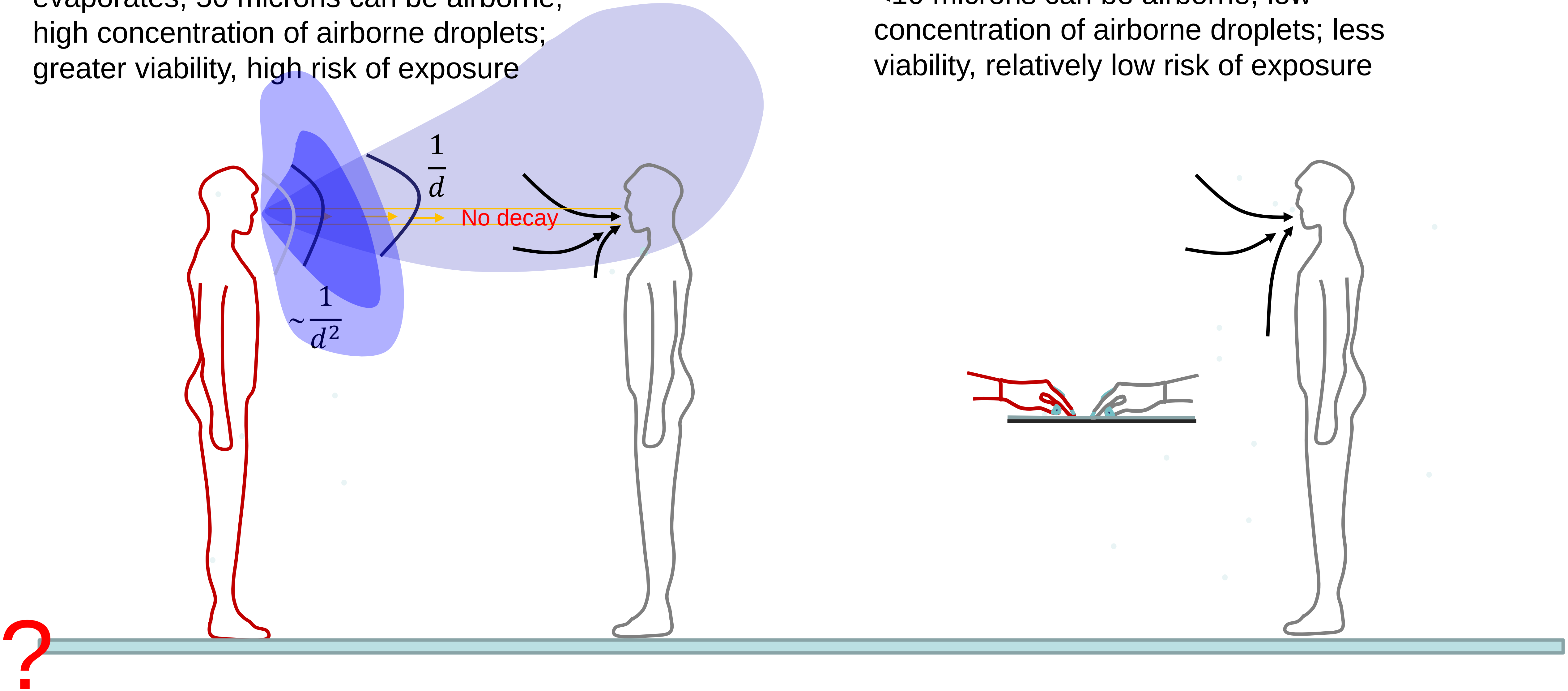


Blocking

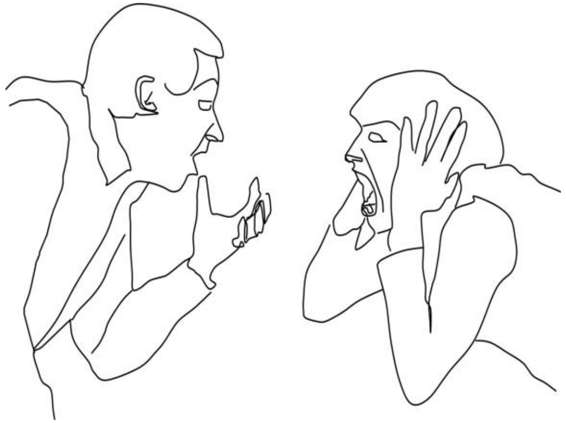
Two different worlds for airborne virus

Close range: air speed (>0.5-2 m/s); droplet stays for 1 s;< 10-20 microns fully evaporates; 50 microns can be airborne; high concentration of airborne droplets; greater viability, high risk of exposure

Distant range: air speed (<0.25 m/s); droplet stays for hours, all fully evaporates; <10 microns can be airborne; low concentration of airborne droplets; less viability, relatively low risk of exposure

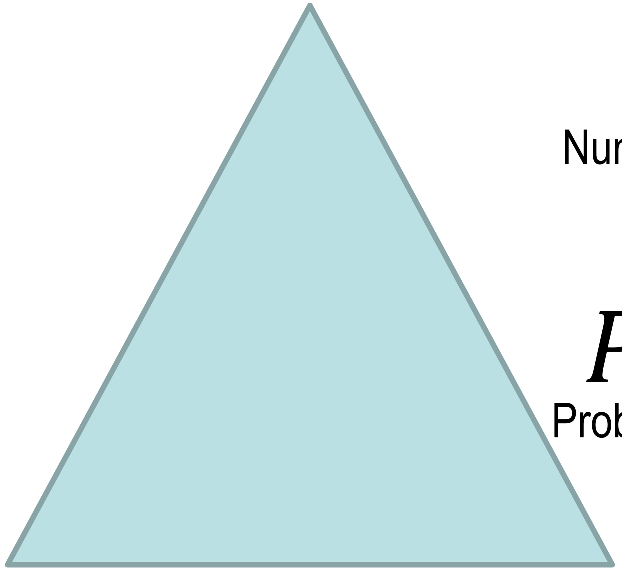


The exposure triangle



Ventilation rate (dilution), air flow (transport), thermal stratification (lack of mixing), turbulence (mixing) (room air distribution design)

Environment



Bioaerosols

People ?

Size distribution at origin; size changes (evaporation), changes in the flow, source (respiratory, medical, fecal), release jet behaviour, voice loudness?

Proximity to source, inhalation, surface touch, self-touch behavior, protection, relative location to the source

Number of infectors

Quanta produced by one infector (quanta/min)

Pulmonary ventilation rate of each susceptible (m^3/min)

Duration of exposure (min

$$P = 1 - e^{-\frac{Iqp\Delta t}{Q}}$$

Probability of infection:

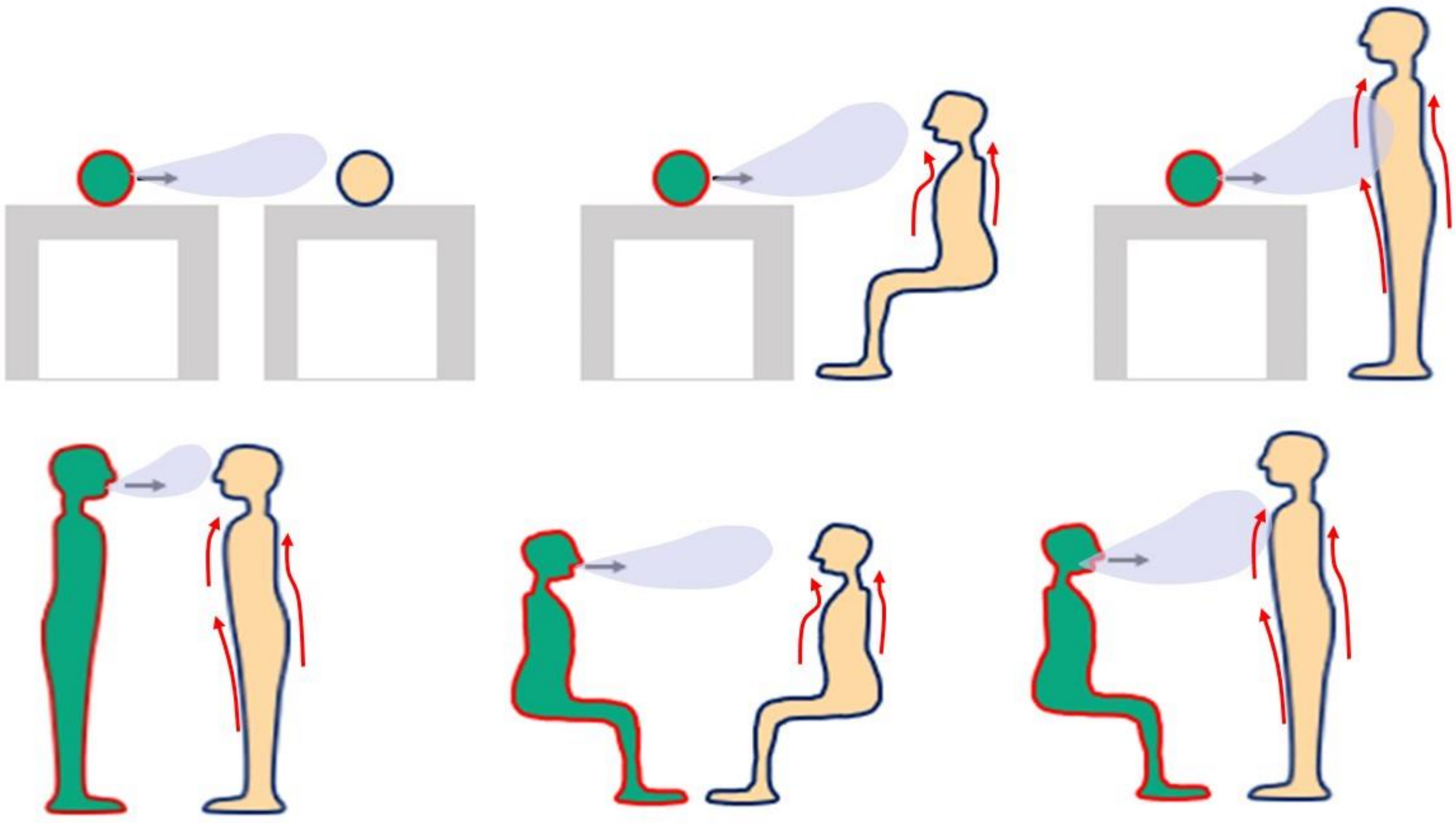
Room ventilation rate (m^3/min)

He R et al. 2020. Aerosol generation from different wind instruments. *medRxiv*.

Gregson et al. 2020. Comparing the respirable aerosol concentrations and particle size distributions generated by singing, speaking and breathing. ChemRx

Relative location, posture and gesture can affect penetration range

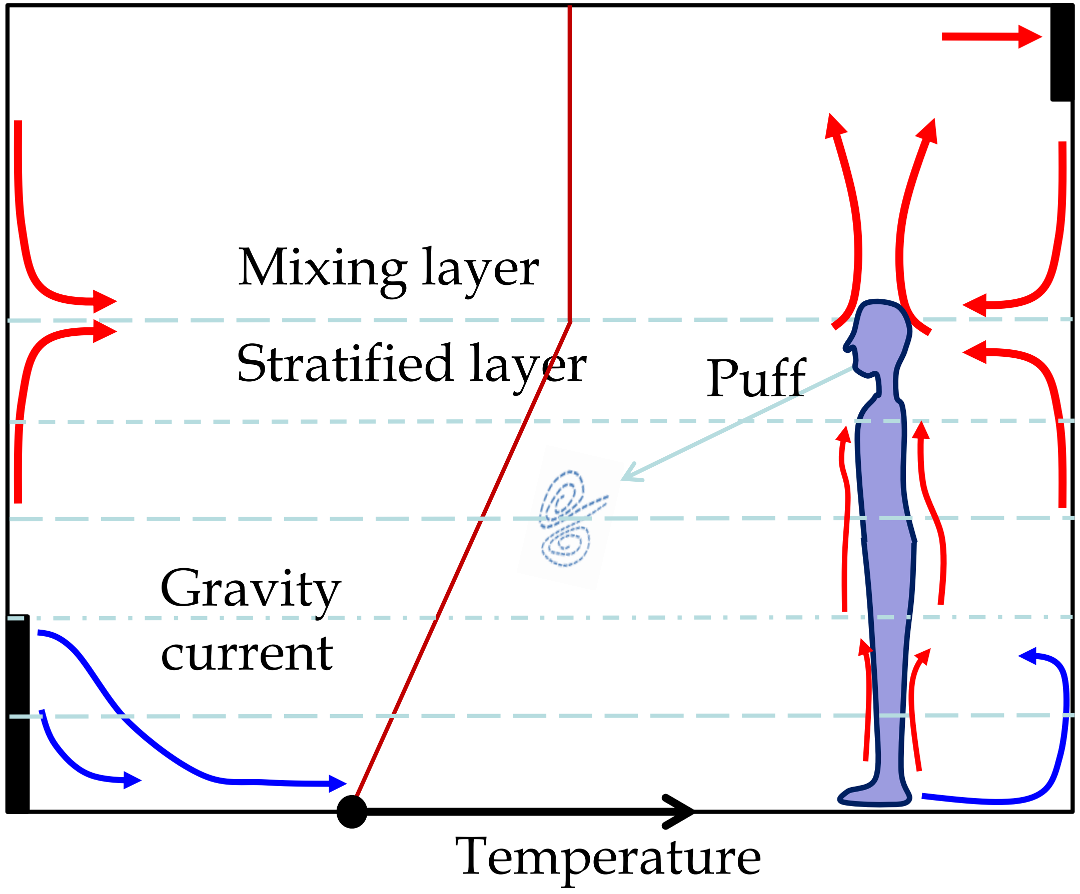
It is a close range, not distance

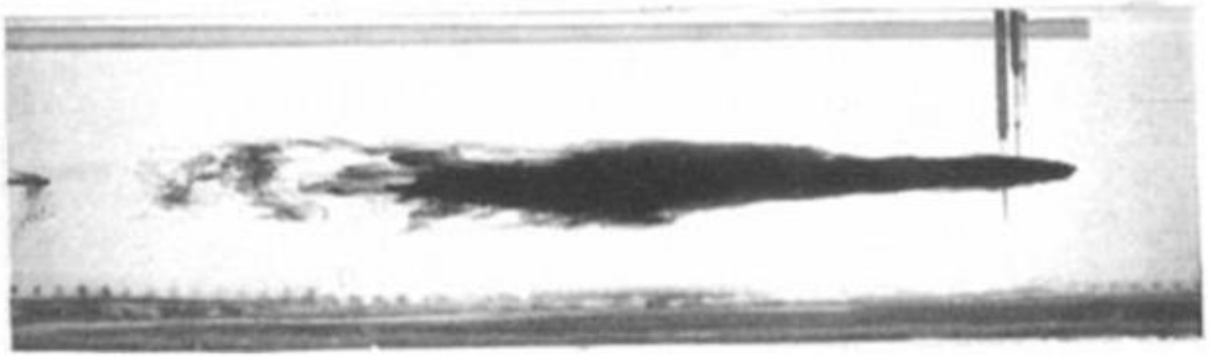


Liu F, Luo Z, et al. Revisiting physical distancing threshold in indoor environment using an infection risk-based modeling. In preparation for submission to a journal.

Room air conditions can also impact on the penetration distance

Inversion in a room may trap the fine droplets

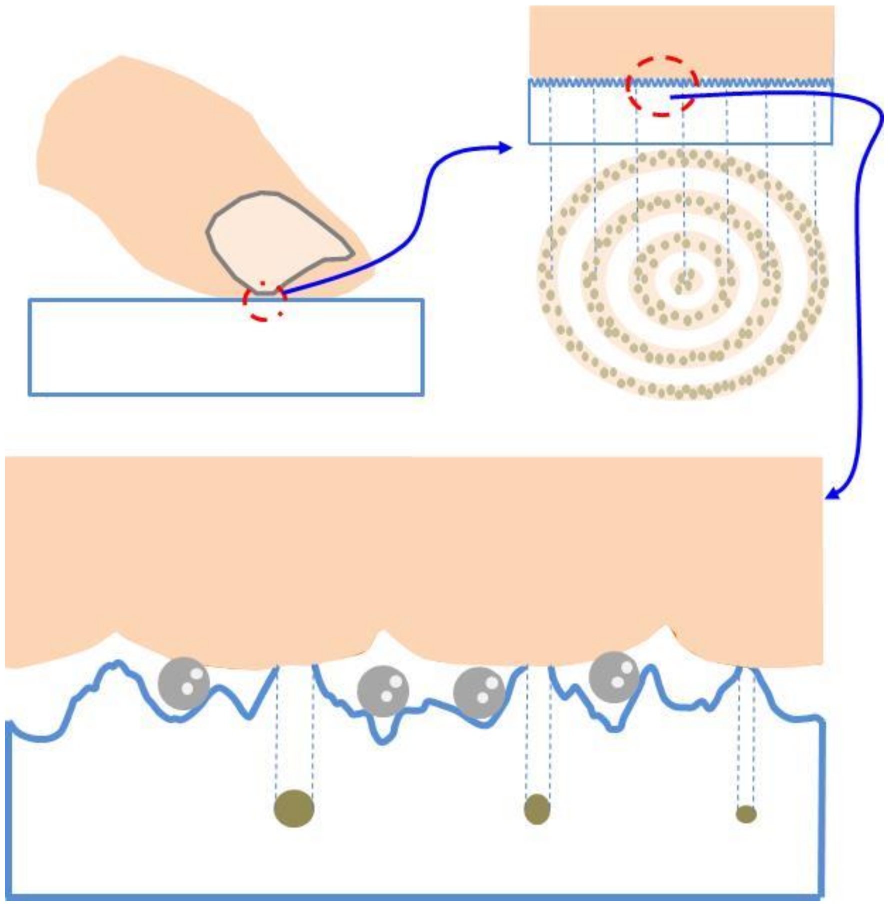




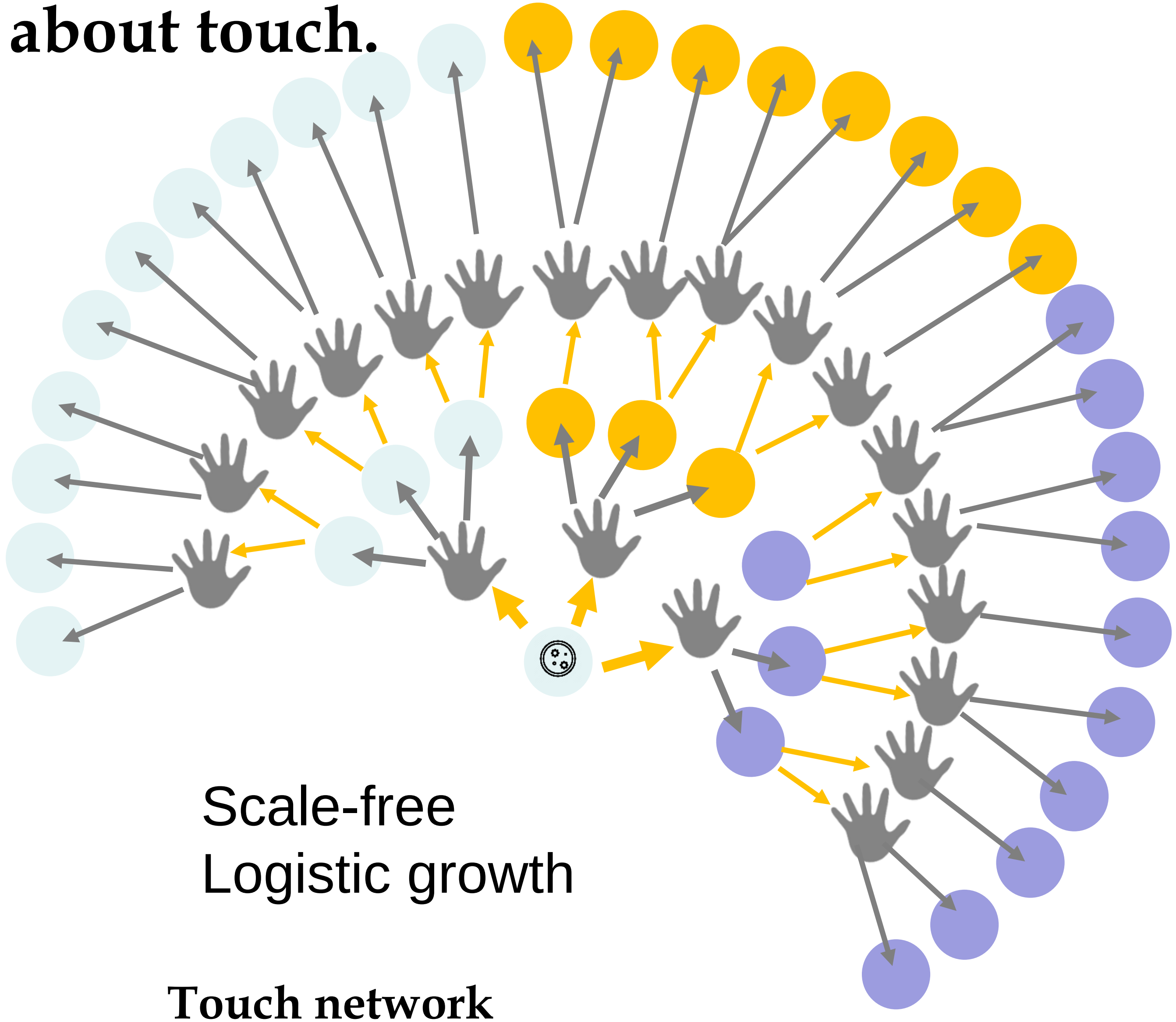
Fonseka SV et al (1998).

Li Y, Nielsen, PV and Sandberg, M (2011) ASHRAE Journal, 53(6):86-88. ; Zhou Q, Qian H, Ren H, Li Y and Nielsen PV (2017) *Building and Environment*, 116, 246-256.; Fonseka SV et al (1998). Journal of Geophysical Research: Oceans, 103(C11), 24857-24868.

Fomite (surface touch route) – all about touch.



Touch microbial transfer



Touch network

Lei H, Li Y, et al. (2018). Indoor air. 28(3), 394-403; Zhao P, et al. 2019. Building and Environment. 158, 28-38; Zhao P, Li Y 2019, Journal of Applied Microbiology, 127(2), 605-615. [Xiao S, Li Y, et al. (2018). Building and Environment, 129, 107-116.

Hand and surface hygiene are paired for fomite route intervention

Number of public surfaces per person

$\frac{N_s}{N_p}$ small, e.g. in cruise ships,

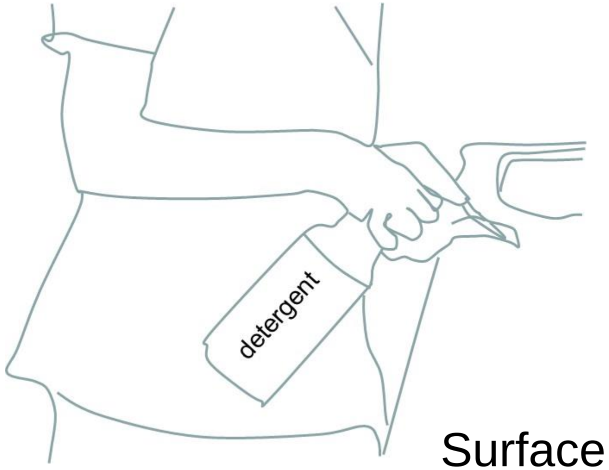
$\frac{N_s}{N_p}$ large, i.e. in non-crowded offices

Average surface touch rate by an occupant [times/hr]

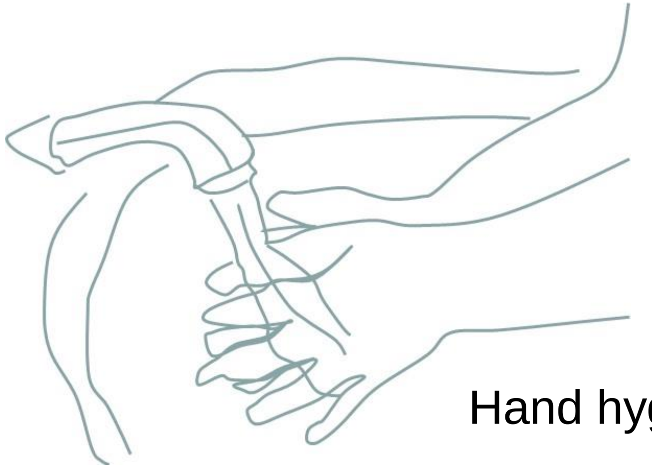
$$\gamma_p \gamma_s \left(\frac{N_s}{N_p}\right) \geq c_p^2$$

Removing rates from hands and surfaces

Removal^2 ≥ Spread^2



Surface hygiene

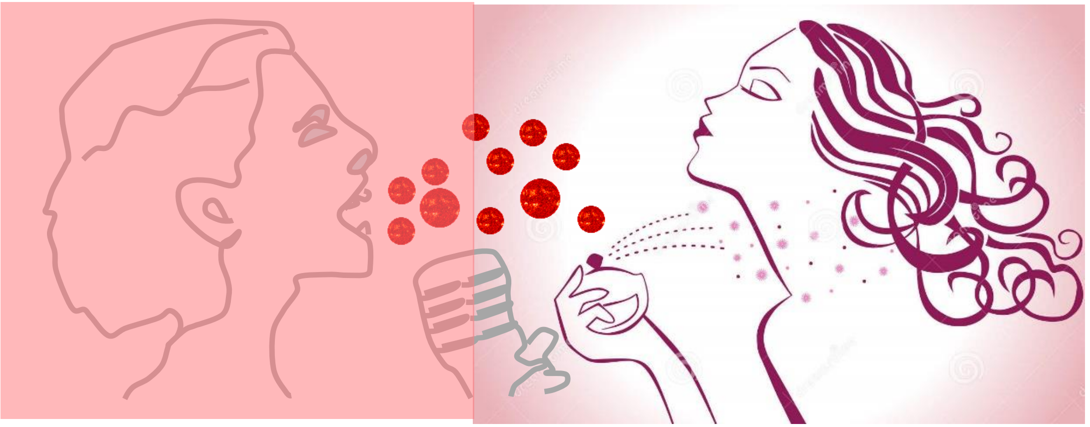


Hand hygiene

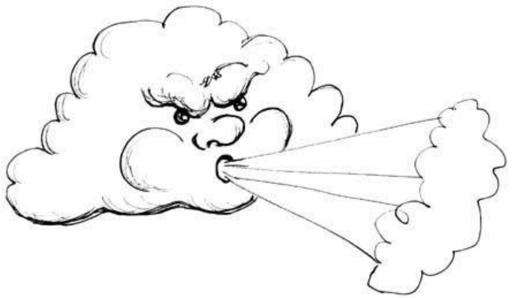
?

Lei H, et al. 2020. Indoor Air, 30(1), 49-59; Xiao S, et al. 2019. Building and Environment, 161,106246. Lei H, et al 2020. BMC Infectious Diseases, 20(1), 1-9.

Should our transmission route concepts be more transfer-focused? ?



- ***(Droplet) spray transmission*** –Not the large droplets, but their momentum, their spray.

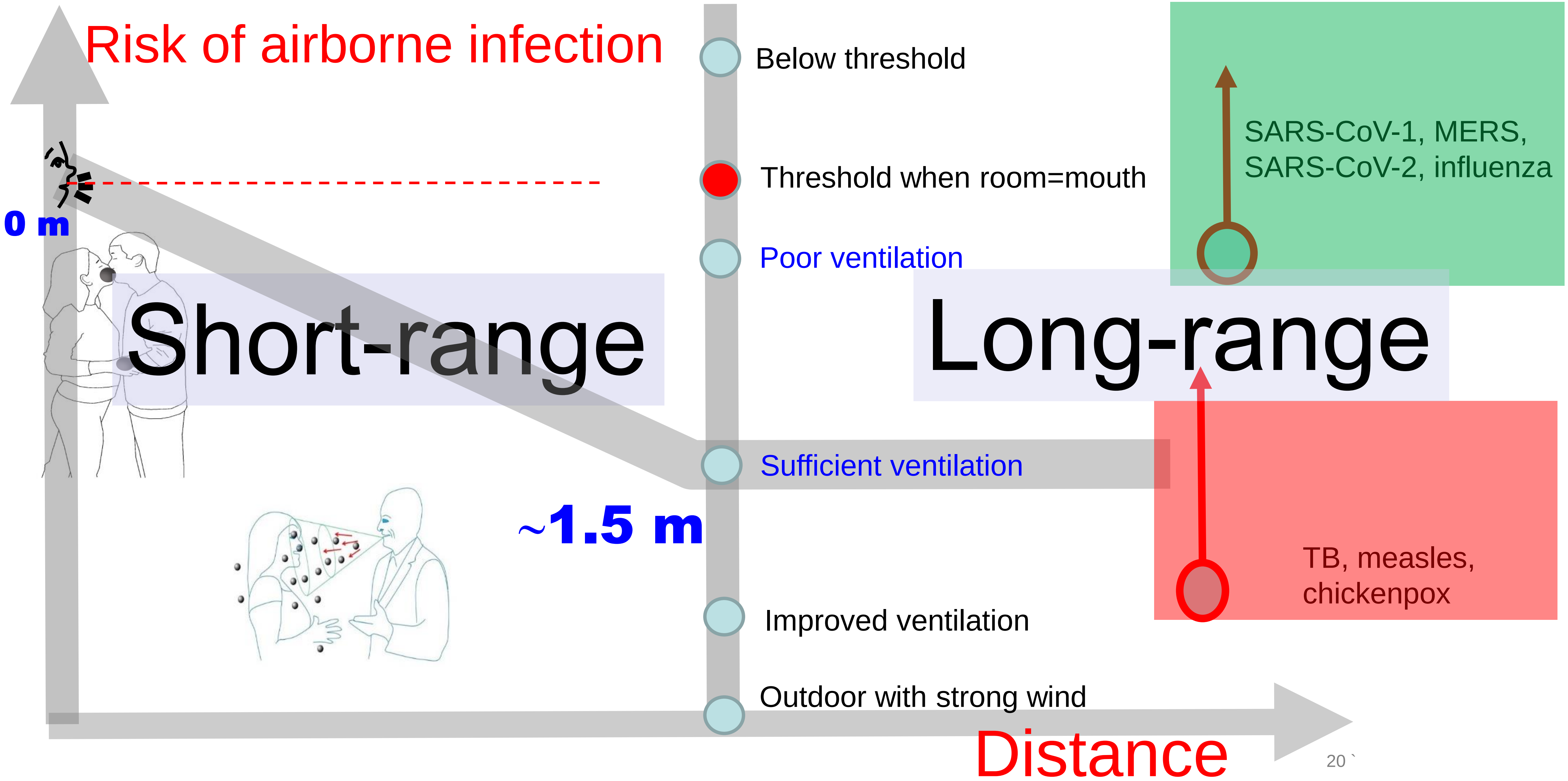


- ***(Air) flow transmission*** – Still air cannot carry anything but the flow of air carries droplets around. Of course, people can go to a room of still air with airborne virus, and inhale, but inhalation is also airflow.

- ***(Surface) touch transmission*** – Fomite will not hurt as long as you do not touch it. Not just inanimate objects, but skins can be contaminated, e.g. our face.

Xie X, Li Y, et al (2007). Indoor Air, 17 (3), 211-225; Liu L, Li Y, et al. (2017). Indoor Air. 27, 179-190; Lei H, Li Y, et al. (2017). Scientific Reports 7: 14826.

Normally non-airborne infection turns to long-range airborne in poorly ventilated spaces



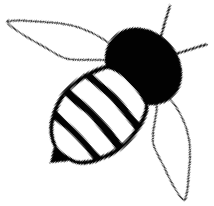
Concluding remarks:

- There is a continuum of the long- and short-range airborne routes. Short-range airborne dominates exposure. Many factors play their roles. **More evidences needed. Human behaviour data lacking.**

- Long-range airborne can be significant when there is insufficient ventilation (e.g. < 3 L/s per person in two studied outbreaks). Sufficient ventilation should reduce distant exposure to be minimum. **More evidences needed.**

- Contribution from immediate surface route remains unknown.

- Faecal aerosols may transmit SARS-CoV-2. Drainage pipes can be efficient carriers. (not covered)



Thank you