Modelling uncertainty in airborne SARS-CoV-2 risks

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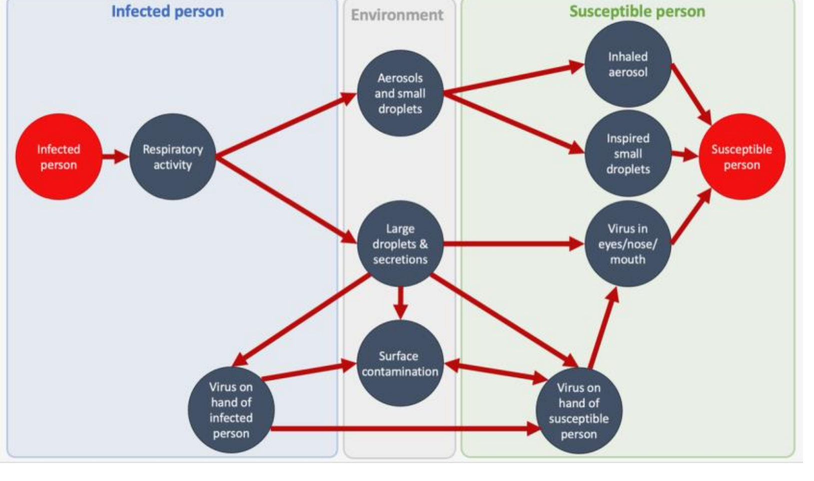
SARS-CoV-2 transmission routes



Airborne – via aerosols (>2m) in a shared room

Close range –via aerosols and droplets (<2m)

Surfaces - via contaminated hands

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Evidence for transmission

- Relative importance of different transmission routes unclear
  - Animal studies show air and surface both possible
  - Outbreaks and contact tracing data show close proximity risk
  - Fomite evidence hard to find, but some association with hand hygiene/cleaning
  - Super-spreading can happen and is associated with higher exhalations
  - Air and surface sampling data patchy, but evidence of virus in small aerosols
  - Airborne transmission associated with poorly ventilated spaces (1-3 l/s/person) – potential for room to room
  - Little evidence for outdoor transmission – crowded/close
  - Modelling (physics, risk models) gives insights into the likely exposure
- Transmission can happen in any setting
  - Risk factors make some settings more/less risky
  - Transmission associated with a setting is not always what it seems

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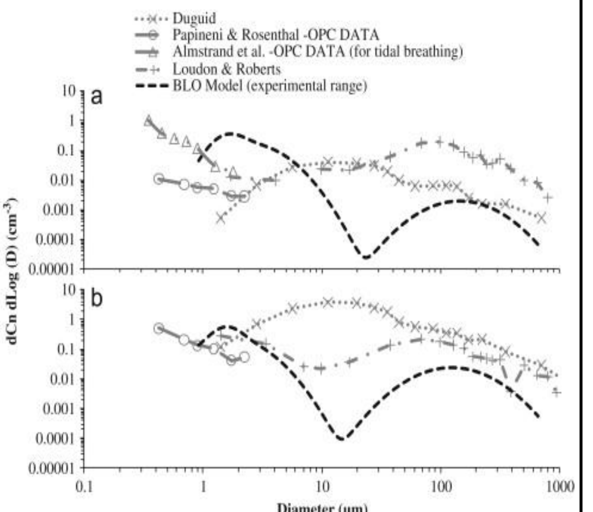
Respiratory aerosols

Johnson et al (2011) J Aero Sci: 12: 839

- Virus around 100nm but contained within respiratory fluids
- Johnson et al suggest 3 modes:
  - Bronchiolar fluid film burst – breathing
  - Laryngeal – voice and coughing
  - Oral – speech and coughing
- Evaporation depends on composition of fluids – salts, surfactants, proteins.
  - final diameter ~0.2-0.5 original
  - happens rapidly



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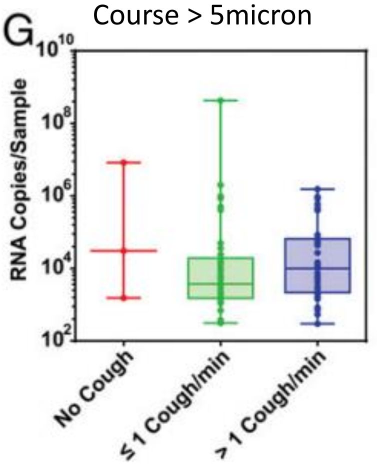
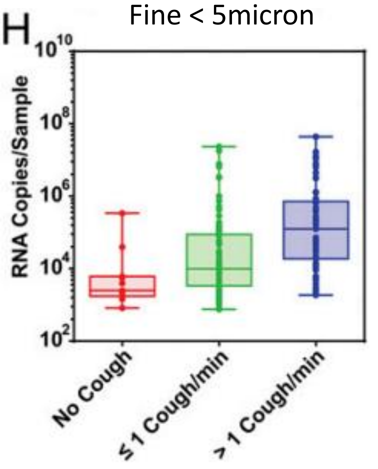
Respiratory pathogens

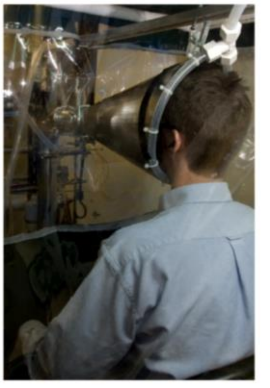
Course > 5micron



Fine < 5micron



Influenza in aerosol



Yan et al, PNAS 2018

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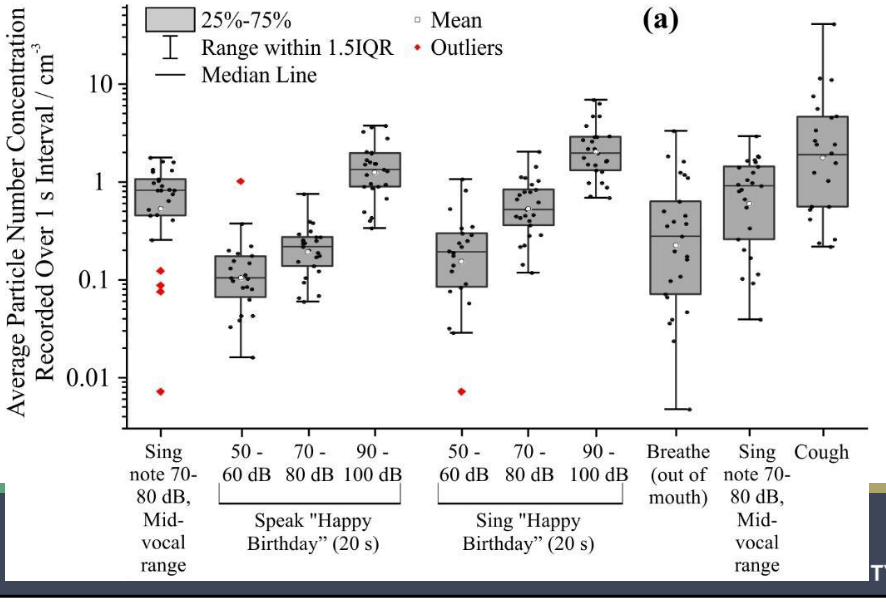
Variation with activity

Gregson et al, 2020



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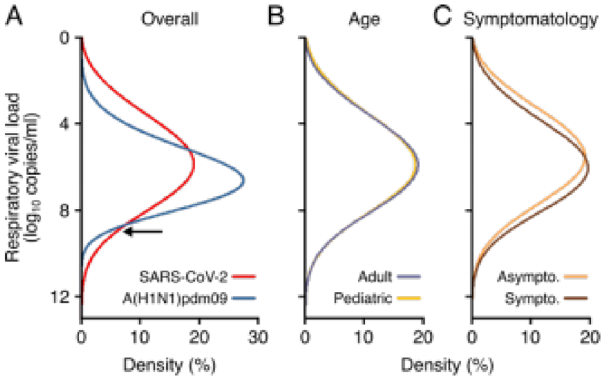
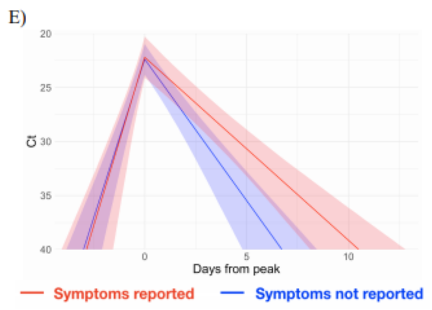
Viral load



Chen P.Z. et al, 2020, pre-print



Kissler et al, 2020, pre-print

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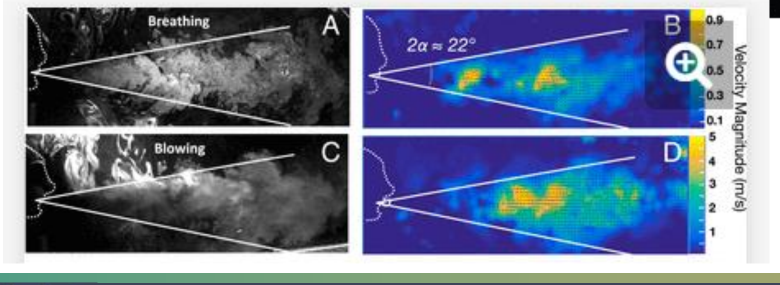
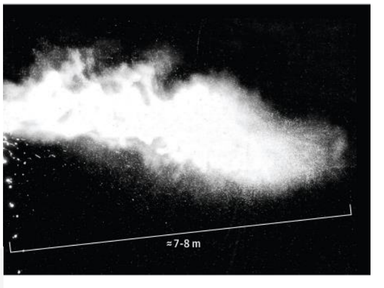
Exhalation physics

- Exhaled breath similar to Gaussian plume
- Particles influenced by thermal plume
- Interaction between droplets for violent ejections – turbulent puff





Bourouiba L, JAMA Insights, 2020

Abkarian M et al, PNAS, 2020

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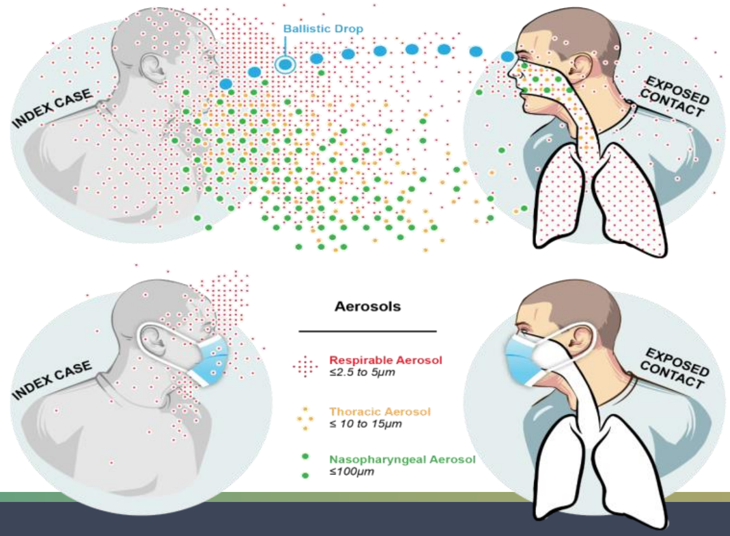
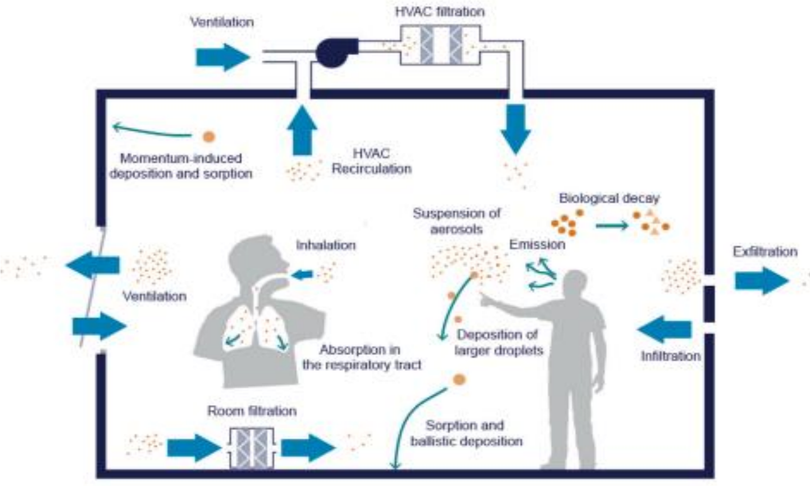
Complexity of aerosols and droplets



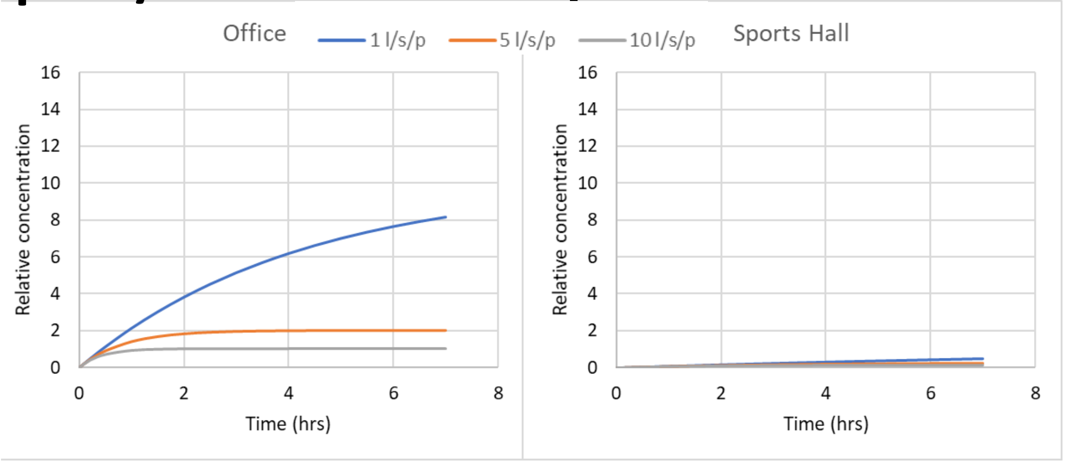
Milton, 2020

Modelling aerosol exposure

- Mass balance models to estimate concentration in air with ventilation rate for given emission
- Exposure from inhalation rate and time
- Simple spaces assume fully mixed flow
- Reasonable estimate >2m from source
- Can include filtration, deposition, air cleaners



Space/flow relationships



20 people, 300 m3 (0.24-2.4 ACH)

160 people, 8750 m3 (0.06-0.65 ACH)

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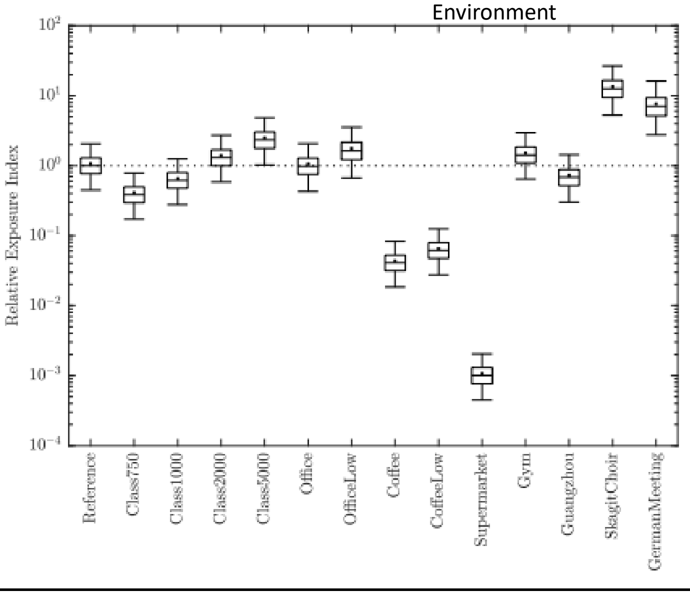
Estimating Relative Exposure

Jones et al (2021) Building and Environment

Relative to classroom designed to 1500 ppm CO2 standard

Depends on:

- Duration of exposure
- Ventilation
- Size of space
- Aerosol emission/ vocalisation



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Linking exposure to risk of infection

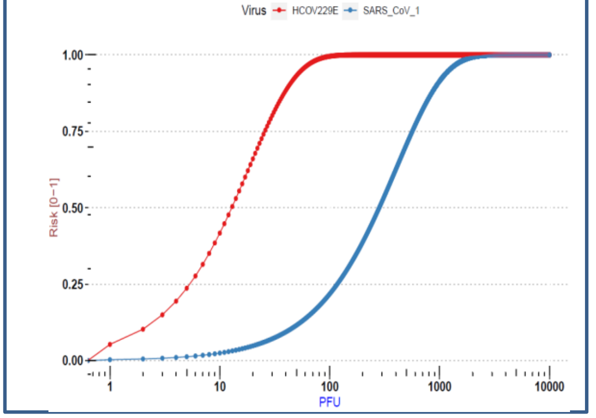
Wells-Riley Approach

$$N_c = S\left[1 - e^{\left(\frac{Iqpt}{Q}\right)}\right]$$

New infections (N_C) with time (t):

- S = number of susceptibles,
- I = number of infectors
- Q = room ventilation rate
- P = occupant breathing rate
- q = Quanta, number of infectious doses generated per unit time

Dose-response Approach



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Quanta values

Disease	Case	Quanta/h	Reported by
TB	Average TB patient	1.25	Nardell et al (1991)
	Outbreak in office building	12.7	Nardell et al (1991)
	Human to guinea pig transmission	0.3-44	Escombe et al (2007)
	Human to guinea pig transmission (MDR-TB)	40,52,226	Escombe et al (2008)
Measles	Outbreak in a school	570	Rudnick &Milton(2003)
Influenza	School cases in Taiwan	66.91 (LN*)	Liao et al (2005)
	Aircraft outbreak	79-128	Rudnick &Milton(2003)
	Human challenge studies	0.11	Bueno de Mesquita et al (2020)
	Data from exhaled breath studies	0.17-630	Bueno de Mesquita et al (2020)
SARs	Taipei Hospital outbreak	28.77 (LN*)	Liao et al (2005)
Rhinovirus	Experimental data of Dick et al 1987	1-10	Rudnick &Milton(2003)

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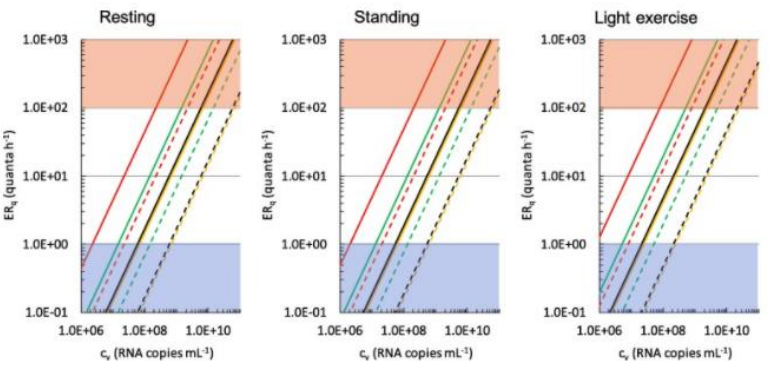
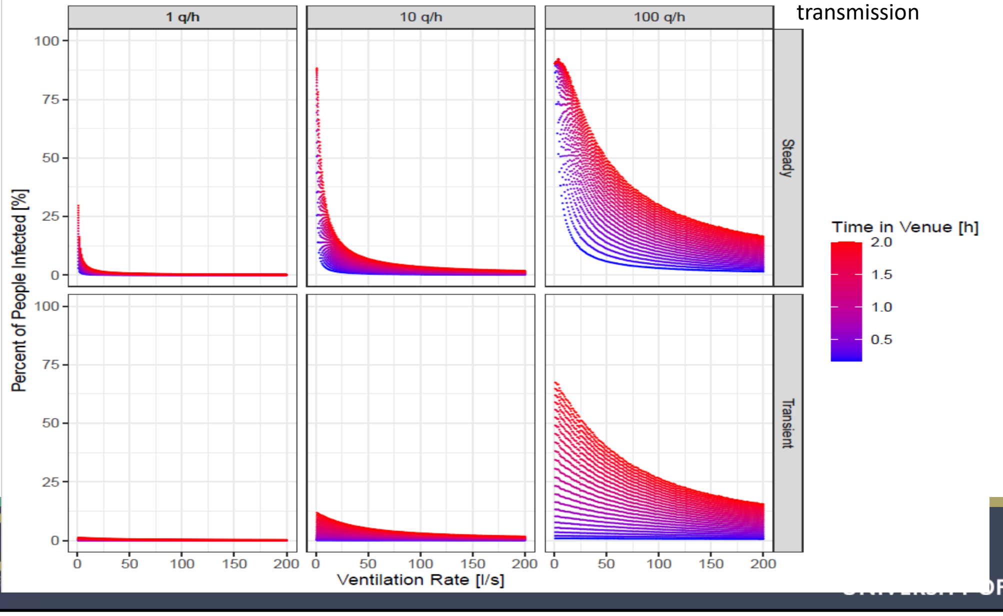
Quanta for SARS-CoV-2

- Buonnano et al (2020) estimated quanta from respiratory viral load (RNA copies) and aerosol generation rate
- Range from 0.1 to 1000 quanta/hr
- Miller et al estimated ~950 quanta/hr for Skagit choir outbreak



Ventilation-risk relationships

SAGE EMG: Role of ventilation in controlling SARS-CoV-2 transmission



Skagit Choir

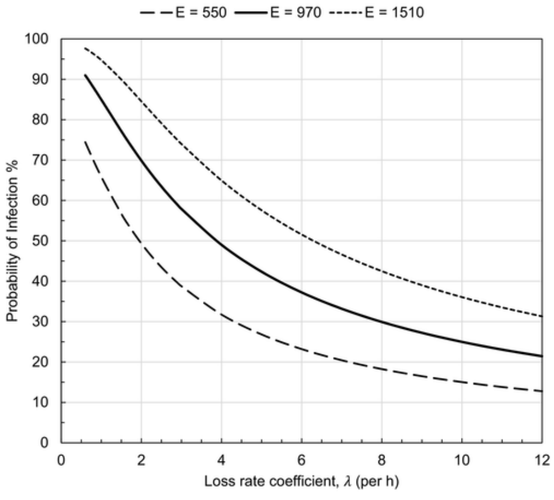
Outbreak

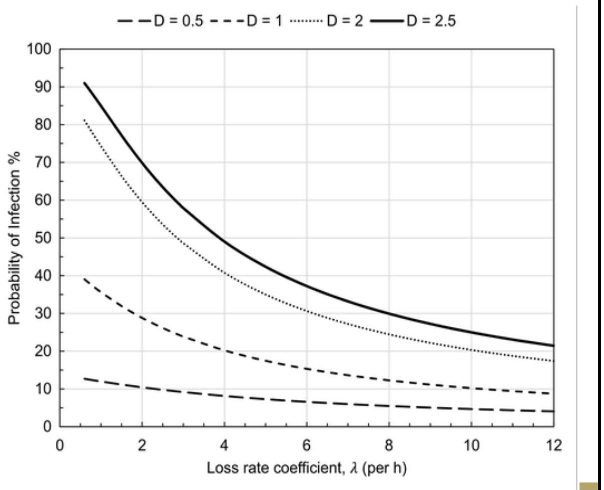
- 61 attendees (~half normal)
- 2.5 hour rehearsal
- 1 infector – mild symptom
- 53 cases, 33 with testing
- Use of sanitizer, no contact
- Distance 0.75-1.4m
- Cases dispersed throughout the room

Model assumptions

- Transient Wells-Riley model
- Monte-Carlo approach to estimate quanta
- 810 m3 room
- Breathing rate 10.8-23 l/min
- Ventilation rate 0.3-1.0 ACH
- Deposition 0.3-1.5, inactivation 0-0.63

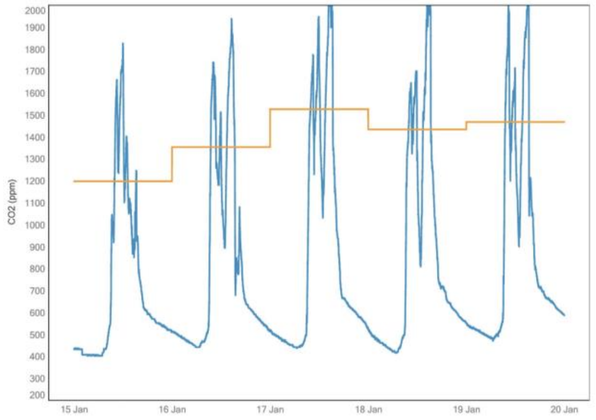
Skagit Choir



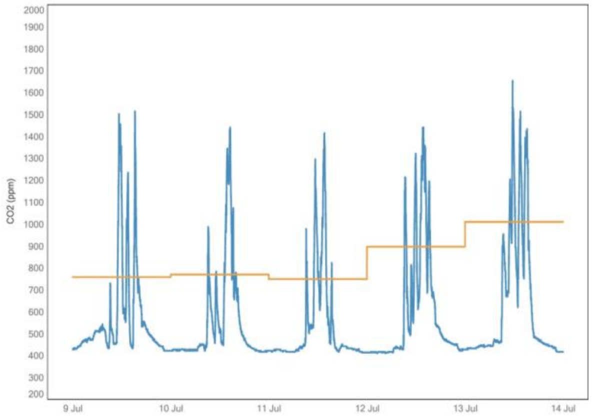


Rebreathed air model

Vouriot et al, Indoor Air, March 2021



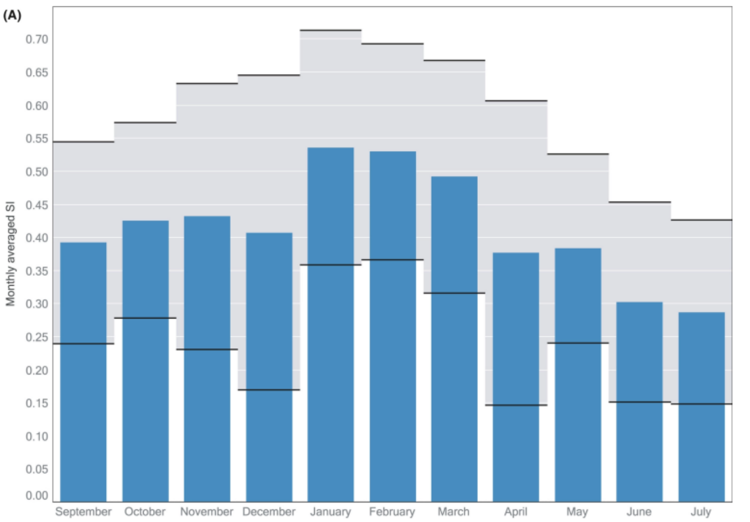
CO_2 levels in January



CO_2 levels in July

Relative risk

- CO2 data from 45 classrooms, 11 schools
- Hybrid ventilation with control based on temperature and CO2
- Risk modelled for 1 quanta/hr
- Airborne contribution within classroom only



Absolute monthly average number of secondary infections.

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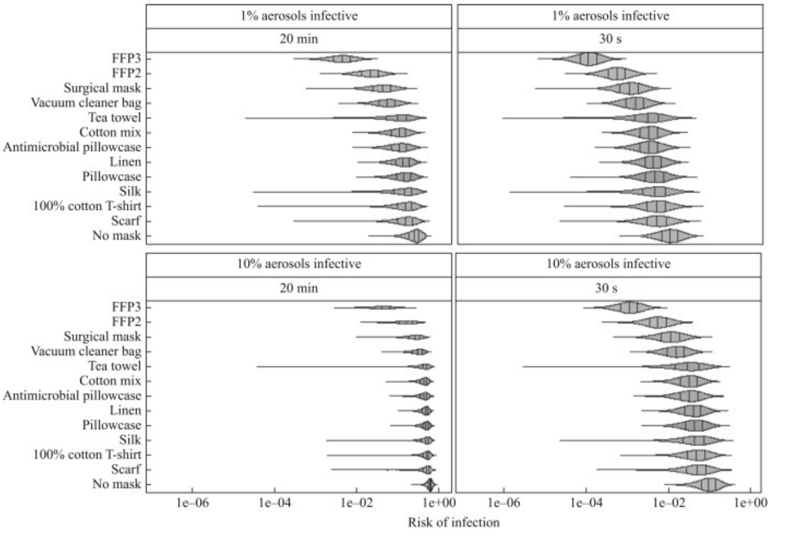
Modelling masks

- Measured RNA copies in room air
- Inhaled dose for different fraction of infectious virus
- Infection risk from SARS-CoV1 & HCoV-229E dose-response



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What about hands?

Depends on multiple parameters:

- Number of microorganisms on surfaces touched
- Frequency of surface touch
- Transfer efficiency from surface
- Area of contact

- Frequency of touching face
- Transfer efficiency to mucous membranes
- Area of contact

- Hand and surface cleaning frequency and efficiency
- Decay rate on surfaces and hands

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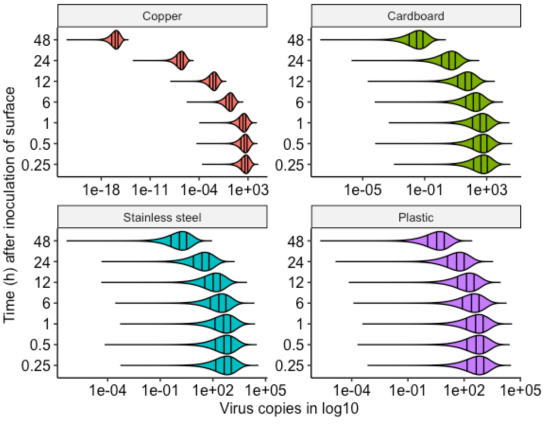
Modelling contact risks

- Uncertainty in viral copies to nose over one hour following surface touch
- Depends on surface decay rate, amount on surface, transfer efficiency, face touch frequency, area of contact
- Lacking data on viral transfers for SARS-CoV-2



M-F King, M Lopez Garcia

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What can we conclude?

- Close-range carries the most virus
- Far-field aerosol is likely to matter for longer duration exposure – may be more frequent?
- Surfaces may matter when sharing a space with an infector
- Significant uncertainty - need more evidence to understand importance
  - Variation in viral load
  - Size of aerosols that contain virus and their emission rates
  - Dose-response and how it changes with route
  - Impact of different mitigation measures

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Thank you

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Any Questions?

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