Environmental Influence on Transmission

SAGE – Environmental and Modelling Group

Consensus from EMG and key issues for SAGE to Discuss / Agree

1. EMG has considered four groups of questions around transmission focusing on:
   - the relationship between time spent in an environment and risk
   - the role of ventilation as a mitigating factor;
   - the relationship between the 2m rule and transmission risk;
   - the risk of transmission from contact with surfaces

   We have considered these in terms of published evidence, some early findings from simulations and some simple risk models.

2. For the purposes of this work, "Environment" is taken to mean the surroundings inhabited by individuals including work, outdoor and indoor settings. We do not consider the natural environment. We consider evidence from healthcare environments and many of the findings are relevant to healthcare; however this paper is not specific to high risk spaces such as hospitals.

3. We have considered transmission through airborne (inhalation), droplet and contact routes, and mitigation measures for these; however it should be noted that the relative importance of these three routes is unknown and may vary with the setting and the infectious person. The evidence to date suggests it is highly likely that short range droplet/aerosol and contact transmission dominate in most settings. *It would be beneficial to collect more detailed data on environments where contract tracing shows transmission has occurred in order to analyse the transmission mechanisms post event.*

How does the length of time spent in an environment affect the rate of transmission?

4. Transmission risk can be considered using a Risk = Hazard x Exposure methodology, where the risk depends on both the amount of virus present and the duration and method of exposure. For all transmission routes the duration of time a susceptible individual spends in an environment where virus is present will increase the probability of receiving a higher dose and hence an increased transmission risk. Short duration contacts even at less than 2m are highly likely to be low risk; a brief (6 sec) conversation at 1m is estimated to be comparable to a 1min exposure at 2m. Many real world close encounters (e.g. passing someone in the street) will be even shorter than this.

5. For all transmission routes the longer an infectious person spends in an environment, the greater the contamination they will leave in that environment for others to come into contact with. Surface contamination could persist for up to 48 hours, contamination in air is unlikely to persist for more than 1 hour unless the ventilation is very poor. As well as enabling social distancing and hence limiting short range transmission, reducing the number of people in an environment and the time they spend there also reduces viral load on surfaces and in air.

6. It is feasible to estimate the influence of time on both exposure and contamination rate as a relative effect for different transmission routes. Estimating actual infection risk is more challenging; while data on other corona viruses can be used as a first estimate, there are not sufficient data on SARS-CoV-2 to confidently estimate infection risks at this

time. Quantifying risk and contamination will require time to develop models and is specific to particular environments. *It would be beneficial to understand which environments are the highest priority to model*. *Data on location and/or job role of those infected may help to identify the highest risk environments.*

Can you rank workspaces by risk e.g. warehouse, factory floor, office? How does this change depending on the number of people and activity?

7. A combination of environmental and human factors act to influence the three transmission routes and we suggest that appropriate mitigation measures should be assessed through a Hazard x Exposure risk matrix approach. We suggest a framework based on human health risk assessment methods (e.g. approaches such as that set out by the US EPA) that could be adapted for different work and public environments and activities. We suggest that this follows work tasks/spaces rather than industry sectors. Environmental factors need to consider the physical layout in terms of how this creates or limits interactions, systems such as the ventilation and sanitation which provide environmental connections between people and operational aspects such as cleaning which mitigate risk. *EMG are currently developing a risk matrix approach to evaluating environments and activities to be shared as soon as possible.*

How can ventilation be used as a mitigation measure?

8. Ventilation acts to mitigate potential aerosol risk at distances beyond 1-2m. It has very limited effects on short-range and contact transmission, other than to possibly slightly reduce the rate of surface contamination. In a well-mixed environment, ventilation rate relative to the room size (usually measured in air changes per hour) together with the number of infectious people are the dominant factors. Where air change rates are low and occupant density is high, airborne exposure will be higher.

9. Improving ventilation is highly likely to be have the greatest effect on airborne exposure in poorly ventilated environments with high occupant density, and increasing fresh air change rates is recommended where practical. It is feasible to use CO_2 sensors as a proxy for sufficient ventilation in some environments. Airflow patterns can be an important factor and transfer of air between spaces should be discouraged. Current guidance issued by REHVA (EU) and ASHRAE (USA) recommends minimising recirculation of air between spaces, with systems set to run on a full fresh air mode where possible.

10. Use of air cleaning and filtration devices may reduce airborne exposure in spaces where ventilation can't be improved; however this needs to be carefully considered in the context of the particular environment and the device. HEPA filter and UV-C based devices are probably the most suitable technologies, but must be sized appropriately for the space and may not perform as well in practice compared to laboratory tests. Devices that emit ozone or other toxic chemicals should not be used in occupied spaces.

11. Ventilation is a precautionary measure that is likely to have a small impact on transmission but can be improved in many environments with minimal negative consequences. To date there is no evidence of airborne transmission in well ventilated buildings. Dilution in outdoor environments means that aerosol risk from respiratory sources is very low. *EMG recommends that a summary of guidance is developed for the*

UK gov website and that professional bodies such as CIBSE provide specific guidance for the industry.

How effective is the 2m rule?

12. The 2m rule mitigates droplet and short-range aerosol transmission. The 2m rule is not an absolute figure; risk decreases with distance and 2m is a distance where risk is considered by many to be sufficiently low. Evidence from modelling studies and simple calculation suggests that exposure could be 10-20 times higher at 1m compared to 2m. Coughing and sneezing is significantly higher risk than simply talking and hence those who have symptoms should make greater effort to maintain the 2m distance and contain coughs and sneezes appropriately. The 2m rule is simple and is a good measure of the distance where the direct person-to-person transmission risk drops significantly although should be seen as a ballpark guide to distancing. *EMG recommends that this rule is retained and used as the basis for developing further mitigation strategies; however, the public could be reassured that short duration closer contacts (e.g. passing a person in the street or in the supermarket) especially in outdoor environments are highly likely to be very low risk.*

What is the risk of transmission via surface contacts?

13. Evidence from previous coronavirus outbreaks, supported by modelling for the SARS-CoV-2 outbreak (see Annex 2) suggests that the infection can be transmitted by touching objects and there is a realistic possibility that this may be the dominant route. Recent work suggests differences in surface survival depending on the material (based on a single paper: van Doremalen *et al.*, 2020) with SARS-CoV-2 surviving longest (up to 72 hours) on plastic and stainless steel, with a significant reduction in infectious titre over this timescale, followed by cardboard (viable up to 24 hours) and copper (viable less than 4 hours). *EMG recommends that further data on survival on surfaces in realistic settings, including indoor and outdoor environments, are needed to make quantitative risk assessments for different cases.*

14. The evidence suggests that cleaning with appropriate materials does significantly reduce virus survival. Exposure is dependent on a wide range of issues: source of infectious agent, cleaning regime, nature of building environment, training or staff etc. The risk factors for each environment should be identified to enable prioritisation by risk and feasibility of mitigation. It is important that a systems approach is taken to understand the interaction between risk factors as this will ultimately determine the overall risk and the opportunity to mitigate. *EMG suggests that cleaning is likely to be a major factor in reducing risk in workplace and public settings and that work should be carried out across the SAGE working groups to understand the impact of cleaning in greater detail and to develop guidance for different buildings/settings*

Overview of Evidence Summary

Relationships between transmission, occupancy and exposure time

i. *How does the length of time spent in an environment affect the rate of transmission?*

15. Evaluating human health risks is commonly carried out using a Risk = Hazard x Exposure approach. In this case the Hazard is related to the amount of virus present in a particular environment and the Exposure is related to the duration of exposure and potentially the method of exposure (droplet, aerosol or contact). Assessing risk in this way is widely used in human health risk assessments for chemical and biological exposure, food safety and in areas such as sanitation and hygiene. Some approaches also include vulnerability, however this is potentially difficult for COVID-19 – whereas some groups are clearly more vulnerable, the groups which are less vulnerable may be facilitating infection and hence including a vulnerability measure may give a false sense of protection.

16. In considering different environments it is necessary to consider the interactions that happen between people: whether these are between employees only, or employees and the public; the frequency and duration of these interactions; and whether interactions involve transfer of information (knowledge work), physical objects (retail) or personal interactions (hairdressers, dentists). It should also be recognised that, within a business, multiple different types of environment and interactions can happen depending on the department, and hence it is not appropriate to simply assess the risk within a whole business as a single environment. Annex 1 discusses this in more detail.

17. Assessing the detailed role of the environment on risk of infection could be carried out using a Quantitative Microbial Risk Assessment (QMRA) framework. This is a modelling methodology that relates the type and duration of exposure to a pathogen with a dose-response model and uses a probabilistic method to quantify risk ranges in particular settings. This is a longer term approach and requires more data; however, initial calculations have been carried out for contact transmission which show it is possible to estimate infection risks (Annex 2).

18. The likelihood of any infection can be described through a dose-response relationship for the pathogen, where the probability of infection increases as the exposure increases. This is typically a beta-Poisson or exponential relationship and may vary with route of exposure. Data do not exist for SARS-CoV-2; however, dose-response for SARS-CoV-1 and HCoV-229E follow these type of relationships (Watanabe *et al.*, 2010).

Ventilation as a mitigating factor - reduces potential for aerosol transmission

i. *What are the key factors that differentiate aerosol risk of transmission indoors e.g. level of ventilation, size of room, level of furnishings?*

ii. *Are there specific mitigations that could work in different types of spaces?*

iii. *Are there air filters that could make a difference?*

19. The use of ventilation as a mitigating factor is a precautionary measure for airborne transmission (see Figure 1. below, from REHVA (2020)) as the role of the airborne route has not yet been established for SARS-CoV-2. It is recommended that the approaches below should be explored and developed until further evidence is available.

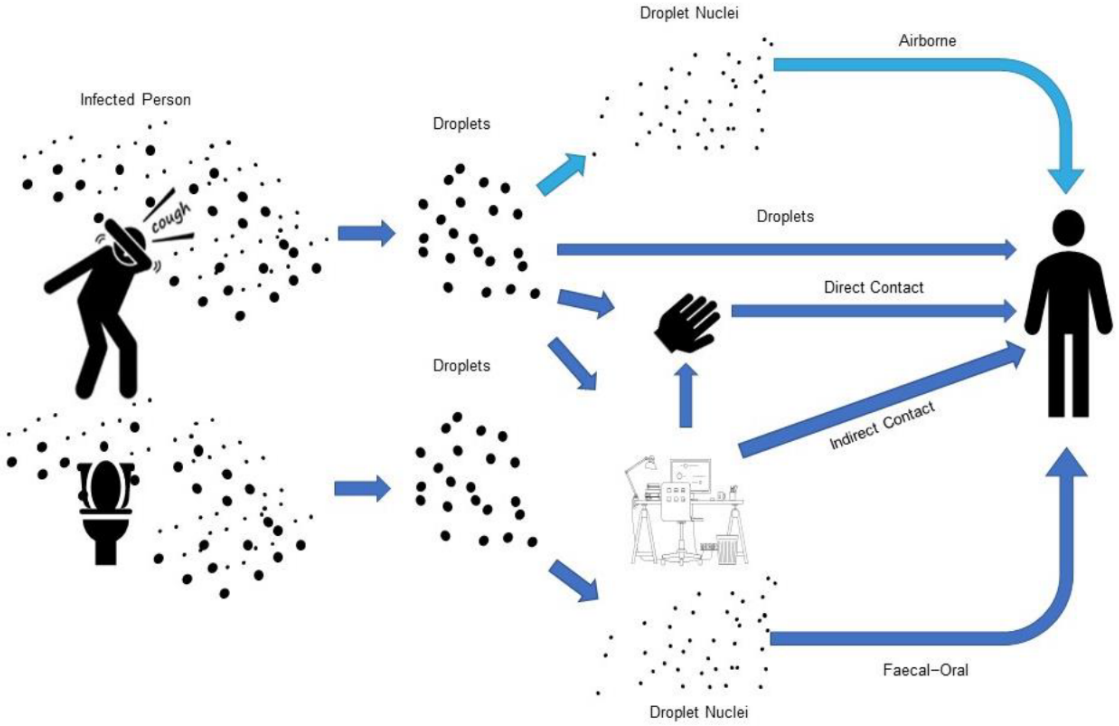

Figure 1. WHO reported exposure mechanisms of COVID-19 SARS-CoV-2 droplets (dark blue colour). Light blue colour: airborne mechanism that is known from SARS-CoV-1 and other flu, currently there is no reported evidence specifically for SARS-CoV-2 (figure: courtesy Francesco Franchimon).

20. Exposure to aerosols (beyond 2m) is primarily governed by the generation rate of the aerosol, the ventilation of the environment, the effective breathing rate of the occupant (which can be treated as reduced with appropriate PPE) and the duration of exposure. Infection risk is typically modelled as a beta-Poisson or exponential relationship with time (Noakes and Sleigh, 2009); doubling the ventilation rate or halving the duration of exposure will theoretically halve the rate of transmission by airborne routes. Evidence for airborne transmission is limited and hard to get, and there is little quantitative data available. Analysis of a restaurant outbreak in China points to possible airborne transmission associated with an extended duration of exposure (~1 hr) and very poor ventilation (0.75-1.04 $l \cdot s^{-1}$ per person compared to the recommended 8-10 $l \cdot s^{-1}$ per person) resulting in 5 new cases.

21. Occupant density indoors is a key factor in transmission. Higher numbers of occupants increase the likelihood of an infectious individual being present and the number of occupants who may be exposed. Occupant number is also often related to ventilation rate as a result of design guidance for building ventilation. CIBSE Guide B2 makes reference to fresh air volume per unit time per occupant from BS EN 13779: 2007, with a value of 8 $l \cdot s^{-1}$ per person for moderate indoor air quality.

22. Although building design guidance typically specifies ventilation rates per occupant, the fresh air change rate (ACR) (the flow rate of outdoor air divided by the volume of the space expressed in units of h^{-1} or air changes per hour (ACH)) is the key parameter that controls exposures. Larger values of the fresh air change rate will reduce concentrations and exposures. Conversely, where air change rates are low and occupant density is high, airborne exposure will be higher. The greatest exposure is likely to be seen when low air change rates are combined with longer residence times indoors and these environments should be the focus of any precautionary mitigating actions.

23. Guidance issued by the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) (REHVA, 2020) and summarised by CIBSE (Smith, 2020) suggests a number of strategies for reducing risk from potential airborne transmission. These include: increasing air supply and exhaust ventilation, using more window-driven natural ventilation in buildings without mechanical ventilation and not using recirculation of air in centralised air handling units. The role of local recirculating air movement is less clear. Although (REHVA, 2020) suggest that local (room level) air recirculation should be avoided where possible, it may be required to supply fresh air to the whole of a ventilated space in some cases, as well as to provide cooling where necessary. The guidance indicates other specific advice for ventilation systems found in some buildings and also indicates measures that are not recommended such as modification to humidity or duct cleaning.

24. Where it is not possible to stop recirculation flows there may be benefit in enhancing filtration on recirculating systems in terms of reducing dose. Whether this is appropriate is difficult to assess because of the lack of quantitative risk assessment. However, where other risk factors such as high occupancy, long exposure time and otherwise low fresh air ventilation are present, this should be considered.

25. The identification of environments with low fresh air ventilation and high occupancy may not be straightforward. Ventilation rates are often difficult to determine, particularly in the absence of central air handling and building management systems. However, monitoring of CO_2 levels may be an effective way of evidencing good ventilation in relation to occupancy. CO_2 has also been used to define the risk of airborne infection (Rudnick and Milton, 2003) including for tuberculosis transmission in South African communal areas and public transport, identifying high risks in prisons and for drivers of transportation (Richardson *et al,* 2014; Andrews *et al,* 2013). There is a general acceptance that CO_2 levels above 1000 ppm are indicative of poor ventilation rates. The provenance of this is clearly evidenced (Porteous, 2011) and corresponds well with a ventilation rate of 8 l/s per person (Appleby, 1990). CO_2 levels set at 1000 ppm in communal areas such as offices and schools have been set as indicators of sufficient per person ventilation rates to provide perceived good indoor air quality and counter human sourced emissions including moisture (BS EN 15251:2007; ASHRAE 62.2 FAQs, 2014).

26. Building management decisions will need to be informed by knowledge of specific buildings and will require the building operator to effectively implement any changes. In larger buildings there may be Facilities Management teams who carry out that role, but in smaller workplaces building occupants may be responsible for operations. As a result, clear guidance and messaging is key. However, professional opinion is complex and is continuing to develop over time. It is recommended that building operators are directed to seek more detailed advice through CIBSE (CIBSE, 2020) and may find helpful guidance from REHVA (REHVA, 2020) and ASHRAE (ASHRAE, 2020).

27. Air cleaning and disinfection devices may be beneficial in environments where it is difficult to improve the ventilation; the addition of local air cleaning or disinfection devices, such as air filtration or ultraviolet germicidal irradiation (UVGI) may be an alternative solution. However ensuring that devices perform to stated efficiency may be problematic and these should only be used as a last resort.

28. Local air cleaning systems, have been shown to be effective in reducing concentrations and exposures when properly sized for the targeted space (using Clean Air Delivery Rate and floor area or volume for example). The Ontario Medical Health Secretariat (2005) considered both portable air cleaning systems as well as fixed local air cleaning systems and concluded that, although not effective at preventing the spread of droplet-transmitted diseases (e.g. influenza and SARS), they may be deployed in situations with a novel/emerging infectious agent whose epidemiology is not yet defined and where airborne transmission is suspected. A range of different technologies are marketed for air cleaning including filtration, UVGI, ion generation, and electrostatic precipitation. Care should be taken to choose products that do not introduce additional problems such as generating ozone, a respiratory irritant. Other practical issues may be important such as noise levels for sufficiently sized units.

29. UVGI in particular can be applied as upper-room devices (Xu et al 2003) creating a zone of UV-C light above the heads of occupants. Airflows carry pathogens through the field inactivating microorganisms without causing harm to room occupants. A modelling study, carried out assuming a similar UV inactivation to that measured for a coronavirus, showed equivalent risk reduction to that which would be achieved by doubling the ventilation rate (Noakes et al 2015). Small consumer air cleaning devices may be beneficial in smaller rooms, although it should be recognised that many of these devices do not have a sufficient flow rate to effectively control bioaerosol concentrations in larger spaces. UVGI application within ventilation ducts may also be a practical approach for contaminated exhaust or in cases where it is not possible to stop recirculation of ventilation flows; however, they are of little benefit against person-to-person transmission when installed in the supply of a full fresh air system.

Mitigation through the 2m rule - reduces droplet and short-range aerosol transmission

i. *Is the "2m rule" an absolute rule related to the maximum travel distance of the virus through air or is it based on an assessment of risk? If the latter, how would this change depending on the likely level of infection in the population?*

ii. *What is the relationship with the length of time spent at distances below 2m with a source of infection?*

iii. *Does the "2m rule" vary depending on whether you are outside or inside?*

iv. *Does the "2m rule" vary depending on positioning (face-to-face, side-by-side, in-front/behind)?*

v. *Does the "2m rule" vary depending on volume of people (e.g. 200 people 2m apart better/worse than 2 people 1m apart)?*

vi. *Is it better to have a simple (2m) rule or a more nuanced rule that allows flexibility but may be harder to explain?*

30. Exposure to large droplets (20 μm and greater) and short-range aerosol (less than 20 μm) at distances 2m and below is primarily governed by the generation rate from the respiratory activity and the duration of time in proximity to the source. Only a small number of studies have explicitly considered dispersion of respiratory sources and quantitatively explored the relationship with distance; these are all based on chamber experiments with manikins, computational and analytical modelling.

31. Liu *et al.* (2017) shows through ventilated chamber experiments that exposure to aerosols (< 5μm) decreases with distance. At 0.5m they indicate exposure is 4-7 times greater than in the room air, while by 1.5-2m the concentration of aerosols is comparable to that in the room air. The concentration in room air is inversely proportional to the ventilation rate. The same study modelled droplet deposition onto the body and showed it reduced significantly with distance. They did not model exposure, but indicated that, at locations under 2m, exposure is the combination of the short-range aerosol, which can be inhaled plus the droplet deposition onto the person as illustrated in figure 1.

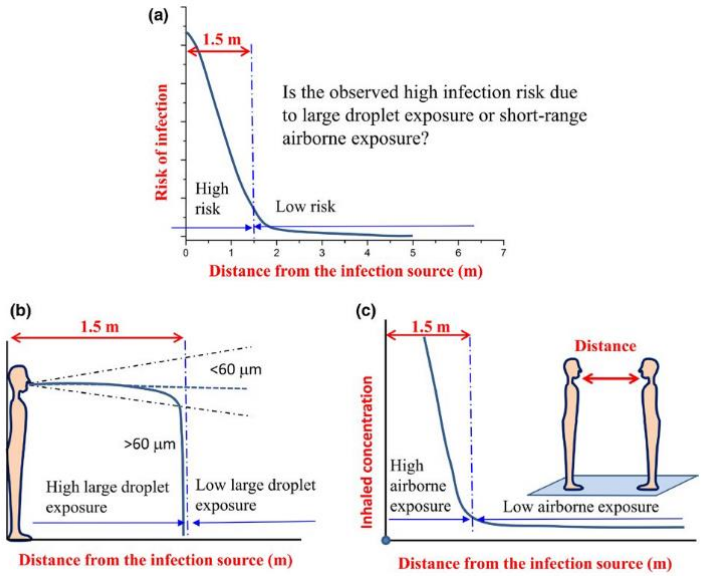

Figure 1: Mechanisms for short-range exposure from (Liu *et al.*, 2017)

32. Chen *et al.* (2020) quantifies short range exposure through inhalation and deposition onto facial mucous membranes for still air using an analytical model. They suggest exposure reduces by over 99.99% at 2m compared to 0.1m. Coughing results in around 20-50 times the exposure at 1.5-2m compared to talking. The study did not consider a sneeze, but data on sneeze particle generation suggests this would be over 1500 times greater than talking, although the reduction in risk with distance is still comparable.

33. SARS-CoV-2 emission rates in exhaled aerosol have been estimated through calculation based on aerosol mass and sputum concentration of 10^8 virus/ml to range from 10.5 h^{-1} for breathing to over 1000 h^{-1} for speaking during light activity (pre-print Buonanno, et al, 2020). Extending this approach to the droplet models presented in (Chen *et al.*, 2020) suggests the viral exposure with time and distance is likely to be similar to the preliminary results in Figure 2 (not peer reviewed). Exposure around 1m may be 10-20 times higher than at 2m, however even at 1m talking is still an order of magnitude safer

than a cough at 2m. It should be noted that this approach assumes that the viral load is proportional to droplet size; data for other infections suggests that this may not be the case, and the viral load may be proportionally higher in the smaller droplets (Milton *et al.*, 2013). It should also be noted that this calculation is with a viral load at the higher end of those measured to date. Values measured by (Pan *et al.*, 2020) from 80 people suggest values between 641 and 1.3 $x10^{11}$ virus/ml with median values around 8 $x10^{4}$ virus/ml in throat swabs, 7.5 $x10^{5}$ virus/ml in sputum swabs. Viral loads at onset were typically around 10^{6} virus/ml. As the infectious dose is unknown it is not possible to state whether the values calculated will lead to infection or not.

34. Short range exposure at distances below 2m in locations with a low air speed is dominated by the plume of particles in the cough/exhaled jet and hence is affected by relative location. A face-to-face close exposure will be much greater than side-by-side or someone located behind. Preliminary CFD data suggests cough particles are predominantly within 50cm either side of the source and move with the dominant flow direction, although this has not been modelled for cross-flow conditions. At distances beyond 1-2m in indoor environments, the concentration and hence the exposure is increasingly influenced by the ventilation of the room; in a well-mixed room at 6 ACH Pantelic et al (2015) showed exposure decreased linearly at around 20% per m from 1 to 4m.

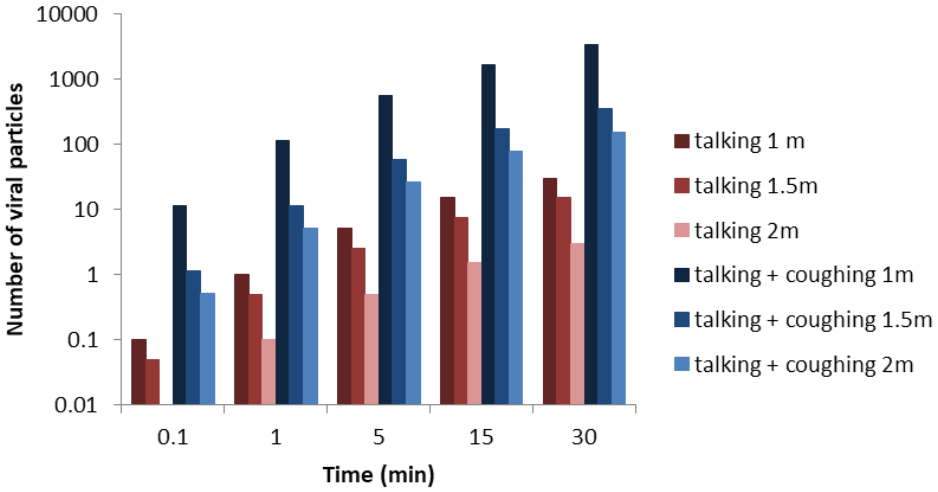

Figure 2: Estimated viral exposure with time based on exposure-distance model (Chen *et al.*, 2020) and viral load calculation (Buonanno et al, 2020). Cough assumes 1 cough per minute. Note log scale. (preliminary calculations – not peer reviewed)

35. Higher flow rates in outdoor environments can potentially transport larger droplets further than 2m. Preliminary analysis through CFD modelling shows the increased transport of larger droplets released in a cough scenario at 2m, however the majority of these would deposit on the lower part of the body, and exposure is constrained to a narrow band directly downwind from the source. As discussed above, time will be a significant factor; a fleeting exposure to a small number of cough droplets outdoors is likely to be far less significant than prolonged exposure in an indoor environment. More detailed analysis is possible through CFD modelling, however these models will take time to set up and run.

Mitigation through surface hygiene – limits contact transmission through contaminated surfaces

i. *What does "environment" mean? Does this mean it lives on all surfaces for 48 hours? How can you mitigate this?*

ii. *How easy is to catch the virus from touching objects?*

iii. *Is there a difference between materials? E.g. Is metal safer than soft furnishings?*

iv. *How prolonged does exposure need to be? Will it live for 48 hours on a door handle?*

v. *How does cleaning impact virus survival?*

36. Exposure via touching contaminated surfaces depends on the concentration of virus on the surfaces, the proportion of surfaces in an environment that are contaminated, the transfer efficiency from surfaces to hands, the frequency with which people touch their face (assuming this is the route for inoculation) and the frequency and efficacy of hand hygiene.

37. Van Doremalen et al. (2020) analysed the aerosol and surface stability of SARS-CoV-2 in comparison to SARS-CoV-1 on various surfaces, using a Bayesian regression model to analyse decay rates. Their samples were generated by nebuliser and the inoculum used was comparable to samples obtained from the upper and lower respiratory tract in humans. Surfaces tested were plastic, stainless steel, copper and cardboard. SARS-CoV-2 was more stable on plastic and stainless steel than on copper and cardboard. A reduction in viable virus titre was observed for plastic after 72 hours (from 2.5×10^3 to 5×10^0 $TCID_{50}$ per ml of medium), and after 48 hours with stainless steel (from 5.01×10^3 to 4×10^0 $TCID_{50}$ per ml). No viable SARS-CoV-2 was measured after 24 hours on cardboard, or after 4 hours for copper. These results were similar to SARS-CoV-1, which the authors suggest indicates that the variation in epidemiological characteristics of SARS-CoV-2, in comparison to SARS-CoV-1, is probably due to other factors. They conclude that fomite transmission of SARS-CoV-2 is plausible since the virus can remain viable and infectious on surfaces for up to 3 days in laboratory conditions (depending on the material). Both FSA and PHE have previously reviewed this issue. Survival data for a variety of coronaviruses has been summarised in the FSA's qualitative risk assessment (March 2020) as shown in Figure 3.

Summary of published studies on coronavirus survival on surfaces

Surface	Virus	Time	Conditions	Reference
PVC	HCoV 229E	5 days	21°C 30-40% Relative Humidity	Warnes et al 2015
PTFE (Teflon)		5 days		
Ceramic		5 days		
Glass		5 days		
Rubber (silicon)		3 days		
Stainless steel		5 days		
Brass (>70%Copper)		<40mins		
Nickel		<120mins		
Plastic plate	SARS-CoV-1	5 days	22-25°C 40-50% Relative Humidity	Chan et al 2011
Polystyrene plate	HCoV 229E	72 hours	21-25°C	Rabenau et al 2005
	SARS-CoV-1	9 days		
Paper	SARS-CoV-1	24 hours*	Room Temperature	Lai et al 2005
Plastic gown		2 days*		
Cotton gown		24 hours*		
Metal	SARS-CoV-1	5 days	Room Temperature	Duan et al 2003
Wood		4 days		
Paper		4-5 days		
Glass		4 days		
Copper	SARS-CoV-2	4 hours	21-23°C 40% Relative Humidity	Van Doremalen et al 2020
Cardboard		24 hours		
Stainless steel		48 hours		
Plastic		72 hours		

*Times varied by viral titre, these are the maximum survival times based on the highest initial viral titre.

Survival time is defined as the time after which the viral titre dropped below the detectable level (detectable level was variable depending on the experiment). For less precise end times this was due to the viral titre reaching the required log fold reduction before that time point was measured.

Figure 3: Survival of coronaviruses on surfaces.

38. Assessing the risk of infection from touching contaminated objects can be evaluated through a QMRA approach as detailed in Annex 2. While this has some uncertainties, based on current data on survival on surfaces the preliminary analysis in Figure 4 (not peer-reviewed) suggests that inoculation could be higher through surface contacts than the values estimated for aerosol/droplet exposure shown in Figure 2.

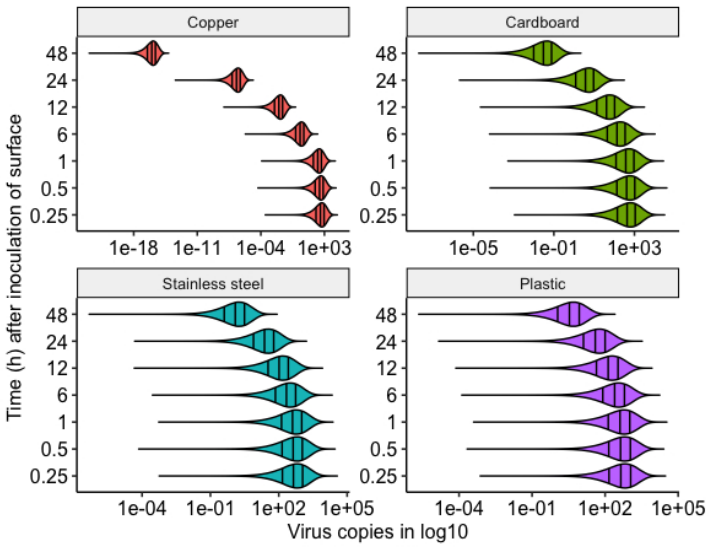

Figure 4: Modelled dose (in viral copies) received by an individual after touching a surface at different times after initial surface contamination, and subsequently touching their nasal mucous membrane during one hour. Note that the different horizontal scales and extensive log range. (preliminary calculations, not peer reviewed)

39. Kampf *et al.* (2020) analysed 22 studies describing the persistence of human coronaviruses such as Severe Acute Respiratory Syndrome (SARS) coronavirus, Middle East Respiratory Syndrome (MERS) coronavirus or endemic human coronaviruses (HCoV) on inanimate surfaces like metal, glass or plastic. Persistence was identified for up to 9 days depending on the virus, but their review of the literature identified that coronaviruses can be efficiently inactivated by surface disinfection procedures with 62–71% ethanol, 0.5% hydrogen peroxide or 0.1% sodium hypochlorite within 1 minute. Other biocidal agents such as 0.05–0.2% benzalkonium chloride or 0.02% chlorhexidine digluconate proved to be less effective.

40. In studies looking particularly at SARS-CoV-2, Wang *et al (*2020) used quantitative real-time reverse transcription PCR (qRT-PCR) methods to confirm the existence of SARS-Cov-2 on 36 surfaces wiped with 1000 mg/L chlorine containing disinfectant. They also looked at sewage outlet samples. Viral culture was performed for any samples positive for SARS-Cov-2 RNA. The authors did not find any SARS-Cov-2 RNA on the 36 surface samples after cleaning. However 3 sewage samples from the inlet of a pre-processing disinfection pool were positive for SARS-CoV-2 RNA and a sample from the outlet of pre-processing disinfection pool was weakly positive. All of the 5 sewage samples from various points were negative by viral culture of SARS-CoV-2. The monitoring data in this study suggested that the strict disinfection and hand hygiene could decrease the hospital-associated COVID-19 infection risk of the staff in isolation wards.

41. Hirotsu *et al.* (2020) reported that all areas cleaned after housing an infectious patient with SARS-CoV-2 were free from viral RNA, suggesting that thorough cleaning is sufficient for SARS-CoV-2 decontamination. However, the study did not take any swabs prior to cleaning so the results are equivocal. Chang *et al.* (2020) observed a 20.4% increase in calls to the USA's National Poison Data System in the period Jan-March 2020 compared to the same period in 2020. This followed CDC advice that, with precautions, the proper cleaning and disinfection of high-touch surfaces should be used to help mitigate the transmission of SARS-CoV-2. Through investigating a small number of these cases they suggested that the COVID-19 pandemic advice was leading to increased inappropriate use of cleaners and disinfectants such as using more than directed on the label, mixing multiple chemical products together, not wearing protective gear, and applying in poorly ventilated areas. The authors suggest that effective communication, labelling and training should be used to reduce this risk.

42. We note that hand hygiene methods may have a significant effect on hand contamination and subsequent surface contamination. Experiments conducted using a bacteriophage surrogate showed that substantially more contamination was found on touch surfaces and volunteers clothing following drying hands using jet air dryers compared to paper towels (Wilcox, Moura 2019). Previous work has also shown jet dryers to cause significant contamination in bathroom environments (Best *et al.*, 2018). Simply recommending regular hand washing may not be enough and the method of drying may also be important too. Given that contamination in bathroom environments appears to be higher than in many other spaces, this should be an important environment for consideration. This has implications for workplace environments which often only have jet dryers.

43. It may be feasible to use other mitigation approaches such as novel surface materials in high risk areas. For example alcohol release door plates have been shown to reduce

contamination for bacterial pathogens and may be a viable option for reducing viral transmission (Best, Parnell and Wilcox, 2017). Innovations to reduce contact through devices such as automatic door opening and contactless operation of systems may also be useful for reducing transmission. It is important that any such measures focus on the priority areas of high touch sites rather than all surfaces and systems.

References

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Annex 1: Ranking workspaces by risk.

Alan Penn 22/04/2020

This note proposes an approach to classifying workplaces and building types according to the risk they present as sites for transmission of SARS CoV-2. It does not define what that risk is for any case since this depends on an understanding of virus transmission mechanisms which is lacking at present, however it does propose a way of ranking according to risks and benefits that may be helpful in deciding how best to release premises and organisations from lockdown.

The note proposes a functional typology of workplaces as well as a spatial/environmental typology.

<u>Functional typology of workplace activities</u>

Different types of workspace support different interaction types between:

a. people and people (knowledge work, education, personal services, retail);

b. people and physical objects (manufacture, warehousing, retail, agriculture/horticulture);

c. groups of people and physical objects (manufacture, construction, mining)

Amongst type a. we can distinguish between those where information is transferred (type a1 – knowledge-based work), those where physical objects are transferred between people (type a2 – retail) and those where customers are handled directly (type a3 – hairdressers, hospitals).

It is also useful to distinguish between workplaces which are employee only and those which require interaction between employees and customers. The latter will also lead to great

public movement in the urban environment and to a greater number of novel contacts. In addition, less information may be available on public customers than employees to support contact tracing.

Different workspace layouts support these interaction types, and typically single organisations/buildings have different areas to support different interfaces between people and people and people and physical objects. For example, a department store will have accounts/buying/HR departments (type a1 – employee only), the main shop floor and café (type a2 employee-customer), a cosmetics area offering facials (type a3 employee-customer bodily contact) and warehouse facilities (type b employee only). All of these will be linked by circulation spaces in which non-programmed interaction between staff and customers take place in the front of house circulation, and between employees only in the back of house.

Some organisation types organise their work and interfaces not only in space, but also synchronise these in time. For example, schools organise classes according to a timetable and synchronise these so that all classes change at once. This leads to synchronised use and so congestion of corridors and stairs. Other examples include conferences and hospital clinics. In addition, offices often operate with office hours, lunch times etc. and this has impacts on pedestrian density both internally in entrance and circulation spaces, cafeteria and breakout spaces, but also in urban space and on public transport.

Spatial and environmental typology

The space within buildings is subdivided to control acoustic, visual, informational and other environmental externalities of activities. These spaces are then linked together by doorways and circulation systems to allow access between different tasks, people and groups, and to allow movement of materials and goods. Where through movement of people or goods is considered a nuisance or risk circulation corridors are provided. Otherwise circulation may pass through open plan spaces.

Spaces can be thought of as shaped by shell, cores, internal partitions and scenery such as furniture. The way that spaces are configured supports the range of interfaces between people and between people and physical objects described in the functional typology section above.

Environmental controls and services are used to temper the environment and to further control externalities of activities. These include air conditioning, mechanical and natural ventilation, acoustic treatment of surfaces and natural and artificial lighting. Natural ventilation and lighting depend upon proximity to an external wall and the depth of the floorplate that can be serviced naturally depends upon floor to ceiling height.

There are a vast number of ways in which the spaces within even quite a small building can be configured, and for any given building function there will be numerous different typologies of building configuration that could support a given functional requirement. However, there are some simple constraints. Movement of people tends to linearity and access to daylight and natural ventilation leads to most buildings being linear with a floorplate depth up to 18m. At depths greater than this mechanical ventilation and artificial light become necessary.

Buildings can be characterised by two dominant forms of circulation, in-to-out movement and all-to-all movement. These patterns of movement may either use the same circulation spaces, or different spaces depending upon plan configuration. Thus, for example in tall buildings most in-to-out movement will be via elevators while all-to-all movement may be through horizontal circulation space on each floor. The way that these two movement types are related will create a potential for mixing between building inhabitants and visitors. These arrangements can therefore affect mixing of communities as well as creating congestion at pinch points at certain times of day. Some buildings separate different groups of users into segregated circulation systems such as clean and dirty corridors in hospitals, or front and back of house in department stores, museums and theatres. In some buildings such as operating theatres and law courts the separation of different building users can be complex.

A risk-based approach to building a safety case

Because of this complexity of building and organisation typologies it may not be meaningful to make general statements about risk at the level of whole organisations or whole buildings, but principles can be set out to allow the SRO within any organisation to build a safety case for their specific organisation and premises to minimise the risk of release from lockdown. The following three questions should be asked:

1. What are the economic, environmental and social impacts of lockdown and benefits of release of any specific work type or interface? For example, personal services that involve close bodily contact are inherently high risk, however for some such as clinical care may it be considered that the benefits require these to continue, while hairdressing or manicure should probably not. Manufacture, construction, agriculture and logistics cannot be performed from home. These sectors should therefore be

considered for earlier release than knowledge sectors where home working provides a feasible alternative.

2. Can the social, environmental or economic benefit be achieved by alternative lower risk means? For example, getting sufficient physical exercise for fitness is important, but this can be done through outdoor physical activity, and so the indoor gym is not essential.
3. What steps can be taken to minimise risk while allowing the primary purpose of the organisation to continue? For example, in knowledge-based activities many tasks can be carried out at distance using digital interfaces and avoiding face to face meeting entirely. In warehousing and logistics regular handwashing and gloves can reduce risk of contamination of objects and of viral transfer to others. In retail cashless payments reduce risk as do online sales. In type c sectors is it feasible to maintain social distancing eg at 2m or does PPE also need to be used?

The following risk benefit matrix can be applied to individual tasks or departmental units within more complex organisations to help develop a safety case for managed release:

	Low benefit	**High benefit**
High risk	**(restrict)** Personal services Indoor leisure (eg pubs) Tourism Hospitality	**(release + mitigate)** Dentist/health care Public administration where face to face client contact is essential Defence, police and emergency services Transportation
Low risk	**(release phase 2)** Internet gaming Garden Centres Outdoor Leisure Creative Industries	**(release phase 1)** Home working in: Public administration Knowledge based work **(release phase 1 + mitigate)** Manufacturing Agriculture Construction Utilities Wholesale trade

The following spatial and environmental characteristics seem relevant to the risk of viral transmission:

<u>Spatial characteristics:</u>

- Differentiation between normal work areas vs pinch points, e.g. entrance areas, stairs lifts, WCs, canteen spaces, meetings. May be critical for otherwise well-spaced activities.

<u>Environmental characteristics:</u>

- General density of occupation (person/m2) (call centre vs warehouse)
- Number of workers (e.g. SME 1-5/ 5 – 50/ 50+)

- Size/volume of physical environment (eg small bike shop vs Halfords) – enabling distancing, but also ventilation/dilution
- Types of space, eg individual rooms/shared spaces/open plan
- Need for movement during work (e.g. assembly worker vs shelf stacker)
- Physical exertion (breathing rate)
- Temperature/RH control (cooled/controlled environments)
- Type of environment control/management (e.g. small SME office with windows vs large office with HVAC and FM team)he risk of transmission

Environmental contamination and risk of infection for SARS-CoV-2

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An estimation of infection risk through surface-hand-nose contacts

1 Introduction

The SARS CoV-2 is known to be transmitted through direct contact between infected individuals and susceptible hosts as well as from an uninfected person touching a contaminated surface. This "environmental contamination" is not restricted to outdoor surfaces but includes those in private residences as well as public spaces (e.g. supermarkets, pharmacies or hospitals). In this brief report, we try to give some quantification of infection risk through the hand-surface contact route with subsequent contact with the nose.

2 Methods

The aim here is to estimate the infection risk due to hand-surface contacts with surfaces contaminated with SARS-CoV-2, given the existing data on this pathogen. We consider four surfaces (cardboard, stainless steel, plastic and copper) that are contaminated at time $t = 0$ (e.g., due to a contact or a cough), leading to an initial concentration (in $copies/cm^2$) on this surface

$$C_0 \quad \sim \quad U(10^2, 10^4).$$

These orders of magnitude have been selected from observations published by Guo et al. (2020) [1] of contamination in different surfaces in an intensive care unit (ICU) and a general COVID-19 ward (GW) at Huoshenshan Hospital in Wuhan, China. We note that concentrations in the order of $10^3 - 10^5$ $copies/swab$ were found after swabbing different surfaces (e.g. floors, computer mice, trash cans, bed handrails, patient masks, personal protective equipment). Since the authors do not report the surface area of the swab, we have assumed that this area could be considered to be around 10 cm^2, leading to a potential interval $10^2 - 10^4$ $copies/cm^2$ for the Uniform distribution considered above. We note that since we are sampling values from the Uniform above to account for uncertainty, we do not need exact values and can work with these rough estimates of the order of magnitude for the concentration that a given contaminated surface could potentially have.

We consider now that an individual touches the surface through a single contact at some time $t > 0$ after its contamination. During $[0, t]$, the concentration of pathogens on the surface will

decay, depending on environmental conditions and the type of surface. We consider four different types of surface comprising *copper*, *cardboard*, *stainless steel* and *plastic*. Half-lives for SARS-CoV-2 on these surfaces have been quantified experimentally by van Doremalen (2020) [5] to be $0.774h$, $3.46h$, $5.63h$ and $6.81h$, respectively. These lead to decay rates of $\mu_{co} = 0.896h^{-1}$, $\mu_{ca} = 0.200h^{-1}$, $\mu_{st} = 0.123h^{-1}$ and $\mu_{pl} = 0.102h^{-1}$, respectively. Then, the concentration of pathogen on the surface at the time of the first contact is predicted to be

$$C(t) \quad = \quad C_0 e^{-\mu_x t}, \quad x \in \{co, ca, st, pl\}.$$

We explore different potential times for this first single hand-surface contact to occur, $t \in \{15min, 30min, 1h, 6h, 12h, 24h, 48h\}$, and model the pathogen transmission by predicting the concentration on the hand after this contact to be

$$C_H \quad = \quad \lambda_{S \to H} C(t)$$

where $\lambda_{S \to H}$ is the surface-to-hand transfer efficiency for SARS-CoV-2. We note that here we are assuming homogeneous distribution of the pathogen over the surface contact area, and that the whole hand surface is involved in this contact. Since this transfer efficiency is not currently available for SARS-CoV-2, we take $\lambda_{S \to H} \sim N_{[0,100]}(7\%, 5\%)$ (Normal distribution truncated on $[0, 100]$) which corresponds to an estimate for Influenza A [8]. The variability in this distribution accounts also for the type of surface (*e.g.,* porous (soft furnishings/cardboard) vs. non-porous (stainless steel or copper)).

2.1 Contact with the nose

After the contact, we analyse the cumulative dose during the next hour for this individual, just by considering the nasal route through hand-nasal mucosa contacts. To do this, we leverage data from [7] regarding the frequency of which individuals touch their faces (and, in particular, their noses) during non-eating activities. We consider that, during each hand-nasal mucosa contact, the dose increases by $\lambda_{H \to M} \tau_{HM} C_H$ where $\lambda_{H \to M} \sim N_{[0,100]}(33.9\%, 22\%)$ from Rusin et al. [4], and $\tau_{HM} \sim N_{[0,10]}(2cm^2, 0.5cm^2)$ [3] is assumed to be the area of the hand-mucous contact. We do not model the decay of pathogen on the hand as a result of these contacts, since we might consider that these contacts during one hour could involve different parts of the hand, and natural decay on the hand is neglected as a reasonable preliminary approximation since we are only looking at a short period of time (1 hour).

Finally, and since a dose-response curve for SARS-CoV-2 is not available yet, we have used a calibrated dose-response curve (Exponential model, $k = 4.1 \cdot 10^2$) for SARS-CoV-1 [6], for computing the infection risk estimates reported here, corresponding to the doses resulting from the computations above.

3 Results

Our probabilistic model leads to Figure 1, which shows the total dose inoculated to the individual's nose, when considering different types of surfaces and different (post-surface contamination) times $t \in \{15min, 30min, 1h, 6h, 12h, 24h, 48h\}$ for the single contact studied. In Figure 2, we plot the mean doses on the nasal mucosa for each type of surface under consideration against when the surface was initially touched. It can be observed how on some surfaces the pathogen rapidly decays within the first hour post-surface contamination whilst other types of surfaces lead to slower decays

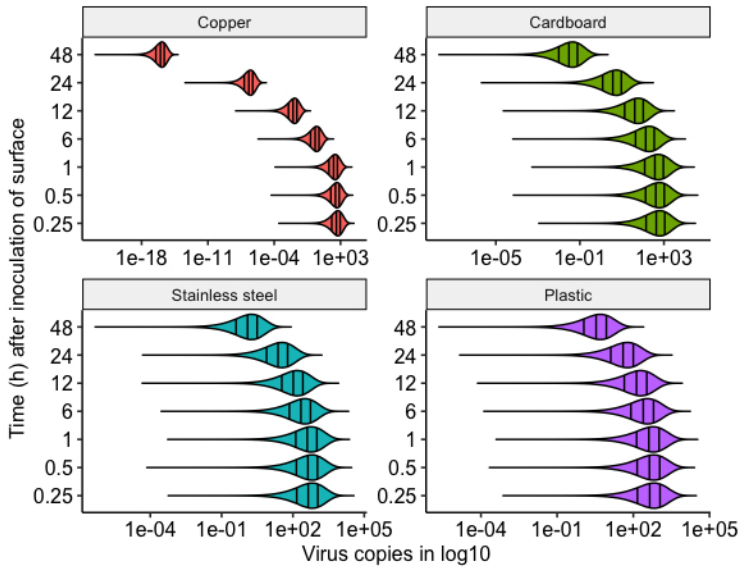

Figure 1: Total dose (in viral copies) inhaled by the individual after touching a surface (*copper*, *cardboard*, *stainless steel* or *plastic*) at time $t \in \{15min, 30min, 1h, 6h, 12h, 24h, 48h\}$ after surface contamination, and subsequently touching their nasal mucous membrane during one hour.

(e.g. stainless steel or plastic), and relatively high doses can be transferred even after $24h$ for these surface types. We also note that the large variability in these dose distributions directly points to the intrinsic stochastic nature of these processes, where many factors play a role (e.g. concentration on the surface at the time of contact, transfer efficiency for the contact or number of hand-nasal mucosa contacts during the following hour).

These cumulative doses, if roughly interpreted as a single instantaneous dose during the $1h$ period (so that the time-dependent nature of the particular inoculation dosing can be neglected), lead to infection risk probabilities which can be quantified through dose-response probabilistic models. The mean (plus and minus the standard deviation) infection risk computed for dose distributions in Figure 1 are reported in Figure 3. As can be observed, the infection risk decays with the contact time $t \in \{15min, 30min, 1h, 6h, 12h, 24h, 48h\}$. While on some surfaces the risk becomes negligible after 6 or 12 hours, materials such as stainless steel or plastic lead to non-negligible infection risks even when the contact occurs after 1 day of the surface becoming contaminated in the first place.

4 Conclusions and limitations

Conclusions:

- The risk of infection through the hand-surface contact route does not seem to be negligible and, in fact, could be significant under certain circumstances (environments with high frequency of hand-surface contacts, or with presence of highly contaminated surfaces).
- Due to the slow decay that has been observed for SARS-CoV-2 on some materials (*e.g.,* stainless steel or plastic), the risk does not seem to be negligible even for (first single) contacts occurring

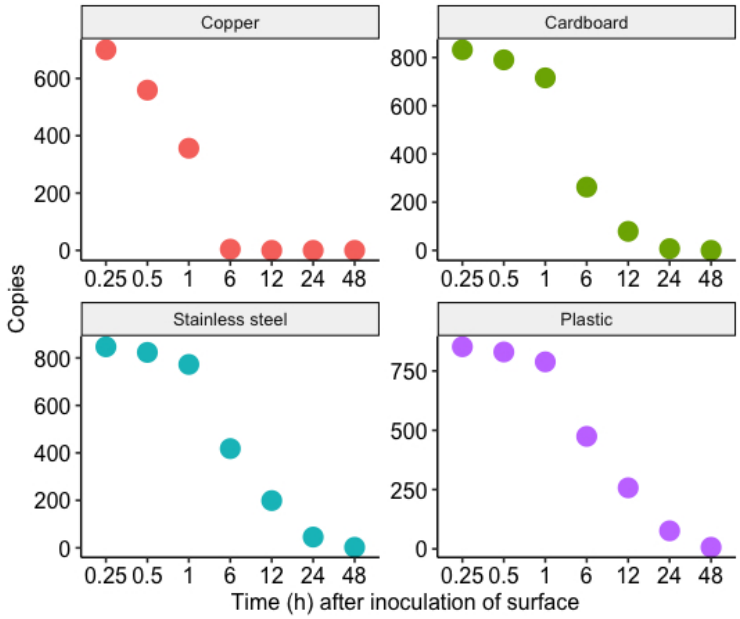

Figure 2: Mean total dose (in viral copies) inhaled by the individual after touching a surface (*copper*, *cardboard*, *stainless steel* or *plastic*) at time $t \in \{15min, 30min, 1h, 6h, 12h, 24h, 48h\}$ after surface contamination, and subsequently touching their nasal mucous membrane during one hour.

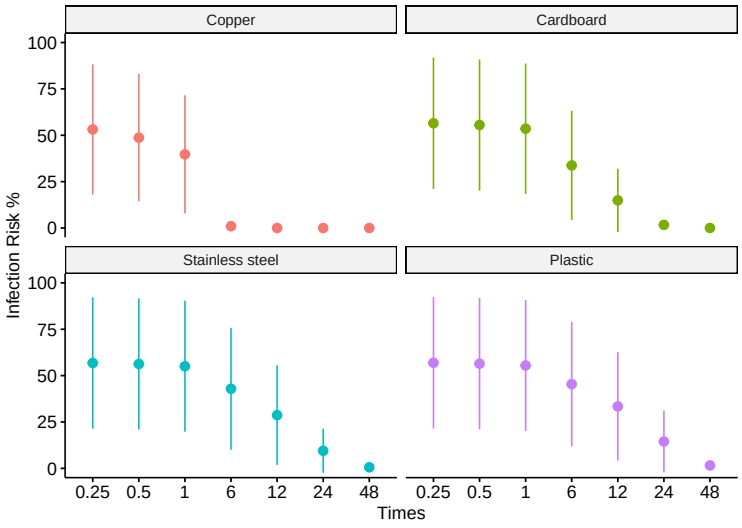

Figure 3: Mean (plus and minus the standard deviation) infection risk ($0\% - 100\%$) corresponding to doses from Figure 1.

up to one day after the surface becoming contaminated in the first place. We note however that, after a single contact, the pathogen concentration on the contaminated surface could significantly decrease. Repeated contacts have not been modeled in this report.

- This risk would directly depend on the initial viral concentration on the contaminated surface. This could be reduced by regular cleaning of high-touching surfaces or by infectious individuals wearing masks so that, for example, deposition from breathing, sneezing or coughing would be reduced.
- Usage of disposable gloves, if correctly used, could help to reduce the transfer efficiency [2] during a high-risk contact such as the one modeled above.
- Usage of alcohol gel can be incorporated into the model and it must be noted that this has an innate variability in the reduction efficiencies ranging from 2 to $4\log_{10}$, which would not necessarily bring the infection risk to 0.

Limitations:

- Hand hygiene has not been incorporated into our model due to time constraints, but it would be possible to do so. A hand hygiene event during the one hour in which hand-nose contacts are occurring could significantly decrease the concentration of SARS-CoV-2 on the hand, and then lead to significant reductions in infection risk. Disinfection of the contaminated surface would also lead to a significant reduction in infection risk, and this could be modeled as well.
- Transfer efficiencies from different surface types to hands for SARS-CoV-2 are not known yet. Moreover, these can vary depending on factors such as temperature, humidity or contact pressure, which also vary significantly between different contacts. This leads to uncertainty in the probabilistic model above.
- A dose-response curve is not known for SARS-CoV-2 yet, so we have used instead a calibrated dose-response curve (exponential model) for SARS-CoV-1 [6], for computing the infection risk estimates reported here.
- Typical behaviour (e.g. number of hand-nose contacts per hour) might change in situations that the individual could perceive as high-risk (e.g. visits to supermarket, public transport, etc). Thus, the behavioural data leveraged from [7] for the model above might not be fully representative of these situations during the COVID-19 pandemic. On the other hand, recommendations leading to individuals being more cautious about the frequency at which they touch surfaces, or their faces, could decrease infection risk.

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