Factors contributing to risk of SARS-CoV2 transmission associated with various settings

PHE Transmission group

Purpose of this Paper

This paper has three objectives:

1. To summarise the current understanding of transmission risk factors;
2. To outline the approaches to understanding where and how transmission takes place and strengths and weaknesses of different study designs;
3. To review the settings where transmission is likely to be occurring and the level of evidence to support this.

The paper considers transmission associated with households, occupational settings, transport and social/leisure settings, and contact patterns and structural factors that are associated with increased risk of transmission. We do not consider health and social care or educational settings in this paper as they are out of scope.

Understanding of principles of transmission, key risk factors and mitigation measures based on evidence in the published literature have been outlined in detail in several previous EMG and NERVTAG papers [1, 2]. The current paper summarises this key published evidence and also draws on further international literature as well as some analysis of NHS Test and Trace data, ONS, REACT data and early case control studies carried out by PHE.

Executive Summary:

1. There are a range of approaches to understanding transmission including outbreak investigations, case control studies, surveillance studies, intervention studies, laboratory studies and modelling, which all have strengths and biases. Different approaches need to be applied and analysed together to identify factors that influence transmission. The majority of data shows correlations and associations, but rarely proves causation, and no single data source provides complete evidence for how and where transmission takes place (high confidence).

2. Transmission risk is influenced by contact patterns, environmental factors and socio-economic inequalities (high confidence). Transmission can take place in any setting but some settings facilitate greater risk of transmission due to a combination of environmental and behavioural factors (high confidence).

3. There is an international consensus that close proximity, prolonged contact, high frequency of contacts and confined shared environments are strongly associated with a higher risk of transmission (high confidence). It is undisputed that a higher contact rate within a population leads to greater rate of transmission, however the relative importance of the various aspects of these factors is not well understood.

4. Viral load is highest at the earliest stages of infection, which occurs around the time of symptom onset to day 5 of symptoms for symptomatic cases. Onward transmission risk is highest at this time (high confidence).

5. The importance of transmission associated with different settings on the epidemic will depend on the likelihood of transmission occurring within a particular environment and the frequency with which people visit that setting. Those that are associated with higher risk factors and are visited frequently by many people are likely to have a much bigger impact than those that may have a higher risk but are visited infrequently by smaller numbers of people (high confidence).

6. Households are environments which are characterised by long duration close interactions, usually with minimal control measures between members of the same household. Transmission risk is very variable in households; a meta-analysis suggests that if there is an infected person in a household, the risk of another household member being infected is 18% on average, with a range of 4% to 55%. This is known as the secondary attack rate. Household crowding and deprivation are both associated with a significant increase in the risk of transmission in household settings (high confidence). More data is needed to understand the demographics of the index case(s) (first infected person) who bring infection to the household.

7. People facing the greatest socioeconomic deprivation experience elevated risk of household and occupational exposure to SARS-CoV-2. Higher cumulative infection rates were observed in those areas that continued to engage in mobility behaviours consistent with commuting for work (high confidence).

8. People working in public-facing occupations are often classified as essential workers, and these occupations involve greater social mixing and greater risk of exposure due to factors such as prolonged working hours, reduced opportunities to practice physical distancing and in some roles a higher likelihood of interaction with an infected person (high confidence).

9. Occupational exposure can vary significantly depending on the nature of interactions that happen within a workplace setting and the level of mitigations that have been applied. Evidence from published literature, ONS data and case control studies suggests infection rates are higher for those who work in hospitality, manufacturing and construction sectors and in warehouses (medium confidence). However, it is not clear how much of the transmission takes place within the workplace, and how much is associated with wider exposures in social, household or transport settings cumulatively.

10. The opportunity for social and leisure interactions and associated transmission has been dependent on local and national restrictions, adherence to those and general chances in behaviour resulting from the advice to maintain social distance [8]. There is likely to be very significant variation in risk of transmission between venues due to the environment and opportunity for close contact between people (medium confidence).

11. Public and private transport enables close interaction between people and facilitates networking. There is limited evidence of widespread transmission within transport environments, but challenges with collecting evidence mean it is difficult to determine the contribution of transmission on transport to the wider epidemic. Risk of infection is likely to vary by mode of transport and travelling behaviour, and appears to be highest among family members or work/social contacts (medium confidence).

12. There are gaps in understanding about where and how transmission occurs. These can be partially addressed by more in-depth analysis of existing data sources, however well-designed studies such as case-control, cohort and intervention studies are essential to properly understand the importance of all the different factors involved in transmission. It is not possible to deliver these studies quickly.

1. Overview of risk factors that determine transmission

In addition to **viral dynamics** (the presence of symptoms and severity of illness, time since date of onset of symptoms, viral load) [3], there are 3 major factors that influence risk of transmission **(Table 2):**

a. **contact pattern** (proximity and duration of contact, the number of contacts, contact frequency, configuration of network of contacts)
b. **environmental factors** (occupant density, ventilation, hygiene practice, likelihood of the activity generating droplets and aerosols). The highest risks occur when multiple risk factors exist together.
c. These dynamics are greatly influenced by the consequences of **socioeconomic inequalities** (i.e. individuals working in public facing jobs, crowded housing, job insecurity, poverty). Socio-economic factors act on all other factors and are mechanistically related to contact pattern, host-related factors and environment **(Figure 3).**

Contact pattern:
Evidence across numerous studies shows that SARS-CoV-2 transmission is facilitated by close proximity, prolonged contact, and high frequency of contacts. There is international consensus that these factors dominate in determining the risk of transmission [1, 2].

The average risk of transmission correlates with the closeness of social interactions: the average per-contact risk is lowest for community exposures, intermediate for social and extended family contacts, and highest in the household [4]. This is related to the nature of contact pattern rather than the setting, with household contacts enabling longer duration and closer interactions and there is evidence to suggest an increased risk of infection in crowded households [2, 12, 16]. However, the number of community or social network contacts can be very high such that these lower risk per-contact exposures may add up to comprise a high proportion of the risk. The number and frequency of interactions in different locations should also be considered against the proportion of work and social settings that are open within a particular geographical area. There is a need for better information on these denominators in order to enable comparative analysis between different locations and the variation with time. When developing mitigation measures it is important to consider not only the number of contacts at a given time, but the number of new contacts, duration, proximity and contact frequency.

Evidence from contact tracing data in England suggests higher secondary attack rates among contacts of cases where there was direct contact (face to face within 1 metre, skin to skin contact for any length of time or being within 1 metre for 1 minute or longer) compared to those who had other close contact (being within 1-2m for more than 15 minutes or travelling in a small vehicle) [8]. However it is important to note that this analysis should be considered in the context of the data available, with the outcomes influenced by the definition of a contact used for contact tracing and a high likelihood that contacts are likely to be unknown.

Environment

Evidence continues to suggest that the vast majority of transmission happens in indoor spaces; recent reviews considering data from several countries found very little evidence of outdoor transmission for SARS-CoV-2, influenza or other respiratory viruses [9, 10]. The small number of cases where outdoor transmission may have occurred are associated with gatherings that facilitate close interactions, particularly extended duration, or settings where people mixed in indoor venues alongside an outdoor setting. It is therefore important that messaging recognises that close interactions outdoors can still pose a risk.

Viral load dynamics

Infected cases have high viral load and infectiousness at the earliest stages of infection, which occurs just before/around the time of symptom onset to day 5 of symptoms for symptomatic cases. Onward transmission risk is highest at this time. Contact tracing and modelling studies also suggest that transmission is highest in the first five days of symptom onset. A contact tracing study from Taiwan and another one from the UK found that most contacts were infected if they were exposed to the infected person within five days of their symptom onset [2, 34, 35]. Faster isolation significantly reduces cumulative contact rates across all contact types [2, 4].

Socioeconomic inequalities

The evidence strongly suggests that the higher risk of exposure and onward transmission due to working and living conditions seen in certain occupations (i.e. public facing occupations) is influenced by factors associated with socioeconomic inequalities [2]. Previous research suggests that although social distancing during the 2009 H1N1 swine flu pandemic was effective in reducing infections, this effect was most pronounced in households with greater socioeconomic advantage [36]. Similar findings are emerging for COVID-19, with the ability to practice social distancing strongly differentiated by household income [6].

Socioeconomic inequalities are associated with risk of infection. This is probably due to a combination of factors including increased exposure, increased opportunity for transmission, increased susceptibility and increased vulnerability. Socioeconomically disadvantaged groups have not been able to reduce mobility as sharply as other groups, and that the places they work, visit and live are more crowded and denser, with higher risk of exposure and higher risk of onward transmission [2] (Figure 3).

Approaches to understanding transmission

Understanding the relative contribution of different factors and settings that facilitate transmission is complex. Understanding this requires data from multiple approaches including outbreak investigations, case control studies, surveillance studies, intervention studies, laboratory studies and modelling. Each of these approaches have their own biases and challenges. **(Table 1)**

Data from contact tracing provides information on the potential exposures that cases have had in the seven days prior to onset of symptoms or date of test if asymptomatic. Data can be used to determine epidemiological links between cases, but it is not designed to confirm where transmission occurred, and it is subject to ascertainment and information bias. This may be for a number of reasons including the nature of how data is collected, over or under representation of some demographic groups, issues with people incorrectly recalling activities, etc. In many cases contact tracing data is incomplete and it is likely to be heavily biased towards people reporting household contacts.

Data from outbreak surveillance is valuable to provide evidence on settings, modes and timescales for transmission, as it may be possible to demonstrate transmission between an index case and the subsequent cases. Outbreak investigations can also yield valuable insights into risk factors, assess effectiveness of interventions to reduce transmission and show how cases are connected together within and between settings. However, an outbreak is a distinct event, and it is not always possible to relate the consequences to other events, and outbreak identification and reporting may be biased towards certain types of transmission which may not be typical. It is also important to recognise that a location associated with an outbreak may not always be the location where transmission happened. For example, cases identified at a workplace may be a result of related social interactions or housing rather than transmission within a workplace setting.

2. Transmission associated with settings

Transmission can take place in any setting. It is important to recognise that the setting itself is not the cause of transmission; it is human behaviour, activities and interactions that occur within a setting that influence transmission. However, some settings facilitate greater transmission due to a combination of risk factors. This may be that the setting enables particular activities or behaviours that are more risky (e.g. singing, aerobic activity, close interactions), is a place where people spend a long period of time (e.g. homes, workplaces, education), or that a setting does not apply certain mitigation measures (e.g. no use of face coverings in some settings). The risk of transmission may also be a function of the effectiveness of any control measures being used in a specific environment. Any sector is likely to have good performers where control measures to prevent transmission have been effectively implemented, and bad performers where little control has been implemented or controls are ineffective. The largest outbreaks from across the world have been reported in residential facilities such as nursing homes, homeless shelters, prisons and ships, as well as some workplaces including meat-packing plants and some factories [2, 6]. These settings often enable multiple risk factors to come together. However, it is also the case that outbreaks are more easily detected in these settings, particularly those with a closed population who have limited external networks and with better links to the health system. In England, in addition to social care and healthcare settings where outbreaks have been common, outbreaks have been observed in many settings including, workplace, educational, and social and leisure settings.

Table 2 outlines factors that may influence the risk of transmission and example tables (Annex A) provide understanding about the risk factors and types of mitigations that influence the likelihood of transmission risk within a number of different settings. It is important to recognise that these are high level and indicative, and within each category of setting there will be some settings that apply mitigation measures well and are relatively low risk, while others that may have more limited compliance which may be higher risk. It is not possible to do a single risk rating for a particular category of setting.

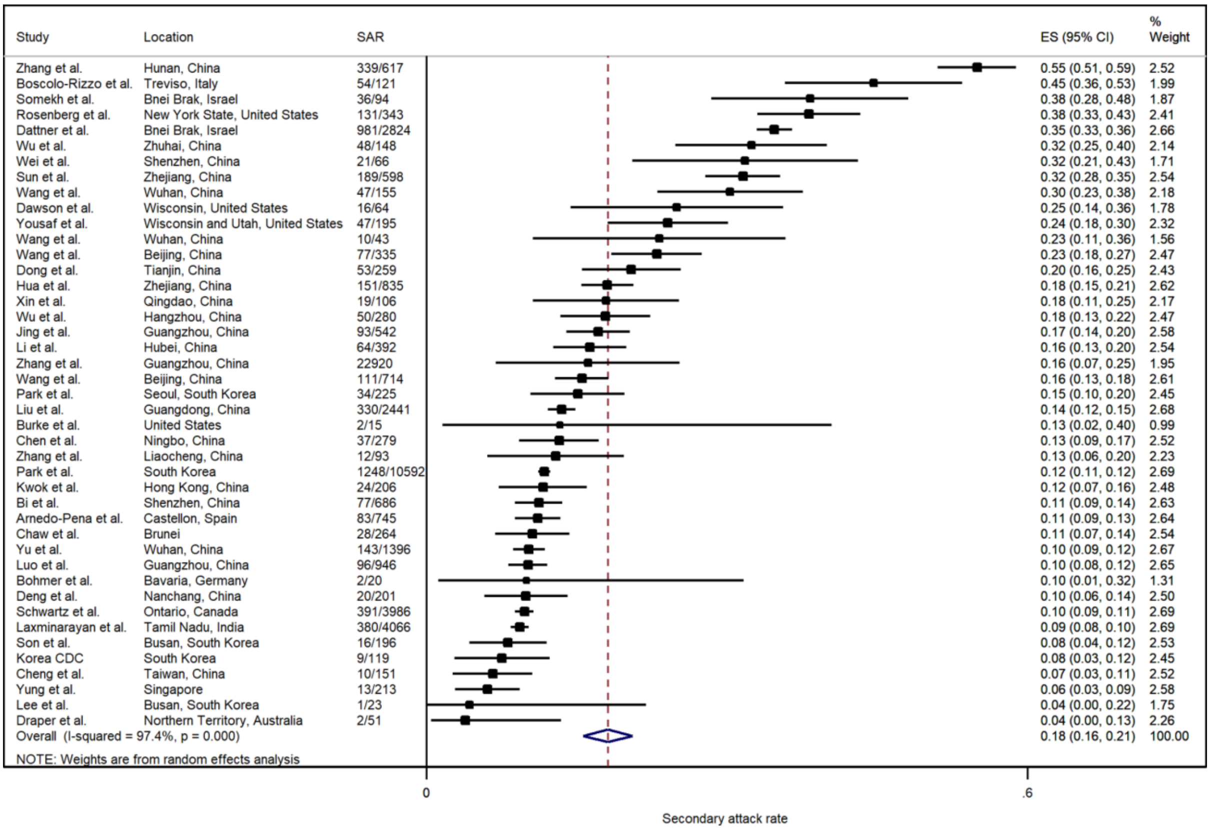
It is also important to remember that transmission linked to a setting may go beyond the physical venue and the activities that happen within that space. Many settings will facilitate other interactions and behaviours including travel and social interactions that happen outside of a particular venue or event.

The importance of transmission associated with different settings on the epidemic will depend on both the likelihood of transmission occurring within a particular environment and the frequency with which people visit that setting. Settings that are associated with higher risk factors and are visited frequently by many people are likely to have a much bigger impact than those that may have a higher risk but are visited infrequently by smaller numbers of people. For example, both households and gyms are settings which may have higher risk factors (see Annex 2), however households are likely to have a much greater influence on the population level transmission as a very large percentage of the population interacts with others in a home environment on a daily basis.

2.1 Evidence for household transmission

International Evidence:

A meta-analysis of international studies on household transmission shows marked variation in secondary attack rates (SAR) from around 4% to 55% with a pooled estimate of around 18% (see figure below). The SAR was higher when the index case was symptomatic (20%) compared to asymptomatic (4.7%). Adults had higher risk of infection than children, and spouses of index cases were more likely to be infected than other family contacts [11].



There is international consensus that those living in larger households have a higher risk of being infected**.** The EpiCov survey in France showed that people living in overcrowded housing (less than 18 m^2 per person for those who share a home) were 2.5 times more likely to have tested positive for SARS-CoV-2. In a Toronto-wide observational study of 14.7 million Canadians, household density was strongly associated with increased risk of infection [12].

According to a recent household data from Switzerland, the chance of being infected by a single SARS-CoV-2 infected household member was 17.2% (95%CI 13.6-21.5%) compared to a cumulative extra-household infection risk of 5.1% (95%CI 4.5-5.8%). Working-age adults (20-49 years) had the highest extra-household infection risk**.** Infection risk from an infected household member increased with age, from 7.5% among 5-9 years to 30.2% among those ≥65 years. Seropositive household members without symptoms had 74.8% lower odds of infecting another household member compared to those reporting symptoms, accounting for 19.6% of all household infections [13].

Other household data from Switzerland showed that after adjusting for individual and household characteristics, infection risk was higher in household members aged 65 or more than in younger adults (aOR 3·63, 95%CI 1·05-12·60), and in those not strictly adhering to simple hygiene rules like hand washing (aOR 1·80, 95%CI 1·02-3·17). During semi-confinement, household members of a COVID-19 case were at very high risk of getting infected, 3 times more than close contacts outside home [14].

In the same household, frequent daily contact with the index case, sharing bedrooms and dining in close proximity has been associated with increased attack rates [2].

Sharing of bedrooms within households increased risk adjusted OR 5.38; 95% CI, 1.82-15.84 [15].

National Evidence

Test and Trace data

Analysis of over 1.2 million cases and their named contacts were identified through Test and Trace showed that 19% of cases had been previously identified as a close contact of another case.

A close contact is defined as “having face-to-face contact with someone less than 1 metre away (this will include times where you have worn a face covering or a face mask), spending more than 15 minutes within 2 metres of someone, travelling in a car or other small vehicle with someone (even on a short journey) or close to them on a plane”. These are likely to be minimum estimates of transmission to close contacts as some secondary cases will be asymptomatic and not all will be tested (although it is likely that a higher proportion of those identified as contacts may seek testing if they develop symptoms compared to people who have not been identified as contacts) and it only includes contacts known to the case.

Four in five cases in England have not previously been named as close-contacts. This is explained by a combination of factors. When there is wide-spread community transmission it is not possible to identify the source of all cases. Contacts are not currently routinely tested and close contacts are likely to be underestimated because they will not all be known to the case and some cases may under-report contacts. This may be due to poor recall, people’s understanding of a “close-contact” or it may be related to fear and stigma of reporting engagement in high risk activities (attending extended family or friend gatherings, or any other activity) or naming a friend or associate knowing that they will be asked to isolate.

ONS infection survey

ONS reported analyses of household transmission in their 14/10/2020 report. The likelihood of a household contact becoming a secondary case varied according to the household size. The likelihood of becoming a secondary case decreased with smaller household size and the number of secondary cases increased with larger household size; in a 2 person household the likelihood of a secondary case was around 18% whilst in a 6 person household the likelihood of at least one secondary case was around 55%. This analysis is consistent with the hypothesis that large households act as amplifiers of infection, once there is an index case within the household. Housing in socioeconomically deprived areas is more likely to be overcrowded, increasing the risk of transmission within the household [2].

The Virus Watch Study

This study shows that of the 242 positive COVID-19 cases, 17% occurred in a one-person household and 83% in multi-person households. Of 149 multi-person households where at least one case was reported, 70% reported a single case, while 30% reported multiple cases within a two week period of one another [30].

The REACT study

According to the recent round of REACT analysis, higher rates of infection were associated with living in deprived areas and in large households. Mutually adjusted models in the most recent period indicated: people of Asian ethnicity, those living in the most deprived neighbourhoods, and those living in the largest households, had higher odds of swab-positivity [16]

Interpretation

- Close contacts of cases are at high risk of infection. Amongst close contacts the risk of transmission is highest among household contacts, then within visitors to the home, then within non household contacts. (High confidence).

- In England most contacts identified through test and trace are household contacts and the risk of transmission is highest in the home (High confidence). However this data does not currently confirm the source of transmission in most cases. (High confidence).

- Transmission risk within the home is higher when the index case is symptomatic and lower when the index case is asymptomatic. (High confidence). This is also in line with data provided in previous NERVTAG/EMG paper [2]. This emphasises the need for symptomatic individuals to be self isolating if they exhibit symptoms while waiting for test results.

- The risk of household transmission is highest between spouses and those sharing bedrooms. (Medium confidence).

- Infection risk is higher among those living in the most deprived neighbourhoods and those living in large households. Large households significantly amplify risk of infection (High confidence)

- The proportion of transmission that is within the home is likely to be highest during periods when other social interactions outside the household are minimised. (High confidence)

- According to previous modelling based on UK data, when children are at school and population-level social measures are in place, secondary school aged children are the most likely member of a household to introduce infection to a household. (Medium confidence) However, international data suggests working age adults aged 20-49 are more likely to be the index case in the household, and infection risk from an infected household member increases with age of the infector. These data suggest that risk of bringing infection to the household may differ according to the social network (contact frequency and number of contacts) of household members outside the household.

2.2 Evidence for transmission in social and leisure settings

International Evidence:
A large community cohort study indicated that increased frequency of exposure to public spaces including shops, cinemas, restaurants and places of worship, and

attending parties, is associated with increased risk of acquiring acute respiratory infections, suggesting a possible important role of casual contact in these settings [5]. Outbreak analysis studies have linked SARS-CoV-2 transmission to events such as parties and weddings as well as locations such as bars and restaurants [2]. Studies have also highlighted clusters in fitness and sports settings. Poor ventilation and crowding have been suggested to be factors in numerous transmission clusters [2]. However, most published studies are from early in the pandemic; it is not possible to establish whether transmission risk has changed over time, for example if mitigations have improved or behaviour has changed.

According to a recent analysis of non-pharmaceutical interventions worldwide, restriction of small gatherings was found to be is the most effective of all approaches, while restriction of mass gatherings is within the top 10 most effective strategies [17]. While this is not explicitly related to social and leisure settings many of which are expected to have better mitigation measures in place than in informal household gatherings, these are places which facilitate gatherings, and enable social mixing between different households.

National Evidence

Contact tracing data:
Secondary attack rates among people identified through the reported cases in the test and trace data as “activity or event” contacts of cases outside the household ranged from 2.7% to 8.4% with attack rates over 7% observed for contacts in public events and mass gatherings, entertainment, day trips and eating out. Analysis from PHE case control studies comparing data provided by cases during contact tracing with general population controls studies [8] (see figure below) suggests that working in hospitality is associated with a higher risk of infection. The study also showed that the fraction of cases likely to be attributable to a particular setting are relatively low in non-household settings which indicates that transmission events are likely associated with many settings and activities. It is important to recognise that this is a hypothesis generating study on which further investigation will be based.

Regional interventions:
Analysis of regional restrictions in England during Autumn 2020, shows that the epidemics under tier 3 restrictions had lower growth rate than before tiers were introduced and most were declining. Tier 2 was less effective, with some areas seeing a reduction in the epidemic, while others seeing just a slowing in the growth rate. The major difference between the two tiers was that pubs and bars were closed in tier 3. This suggests an association between these settings and the rate of transmission in locations with a high disease prevalence.

Interpretation

- Social and leisure settings are environments where transmission can take place and, in some cases, have factors (e.g. lack of face coverings, longer duration of exposure, activities that generate more viral aerosols) that may increase transmission risks (high confidence).
- Many social and leisure settings are environments which facilitate interactions between members of the public and hence are more networked than households and many occupational settings. This means that they may

provide connections between a greater number of people than many other settings, potentially enabling transmission between social networks. (high confidence).

- It can be difficult to ascertain whether transmission occurred within some social settings as they are environments that can have transient interactions with multiple people. Tracing people who were present together in a setting and determining how they interacted can be very challenging, especially where there is significant under ascertainment of contacts.
- There have been substantial and frequent changes to which social and leisure settings have been open during the pandemic and the rules that govern their operation as the rates of infection have changed regionally. As such it is difficult to examine the time course of actions compared to infection rates to establish the role of particular settings.
- However, PHE data over August, September and October indicates increased odds of being a case among people working in the hospitality sector, which is likely related to a combination of contact frequency, working and living conditions [8]. Occupational settings and risk is further discussed in the next section.

2.3 Evidence for transmission in occupational settings

*The evidence on health, social care and the education sector is not discussed here.

International Evidence:

Outbreaks of COVID-19 have been observed in several occupational settings including call centres, slaughterhouses, meat processing plants, factories, warehouses and building sites. Outbreaks have been associated with working in confined indoor spaces, lack of social distancing and shared welfare facilities [6, 7]. Working indoors, meetings with multiple people in the same room and sharing work facilities (such as canteens, kitchens and toilets) are also highlighted by ECDC as risk factors [22].

Food processing has been cited as a specific setting where risks are higher, with multiple large outbreaks identified worldwide. These settings have a number of complex risk factors including low temperature environments (which may also have low ventilation rates) which may promote virus survival as well as exogenous factors which have been identified such as shared transport, multi-occupancy housing and nature of employment (for example being on a zero-hours contract may mean not having sick leave or any benefits that is linked to employment leading to undue pressure to work while sick or not being able to quarantine as a contact).
In Ontario, Canada, from January 21 – June 30, 2020, there were 199 workplace outbreaks; 68% of outbreaks and 80% of outbreak-associated COVID-19 case were in three industry sectors: Manufacturing, Agriculture (including Forestry, Fishing, Hunting), and Transportation/Warehousing. Household transmission occurred among 31% of outbreak cases, resulting in a 56% increase in workplace outbreak-associated cases when burden of household transmission is considered [18]

In Sweden, the relative risk of being diagnosed with covid-19 differs between different occupational groups. The highest relative prevalence was found among the occupational group taxi drivers followed by some specific groups like pizza bakers, delivery persons and bus and tram drivers. For the occupational group taxi drivers and bus drivers the relative risk was 4.8 times higher compared to other occupational groups. The occupational group with the largest number of cases was cleaners [33].

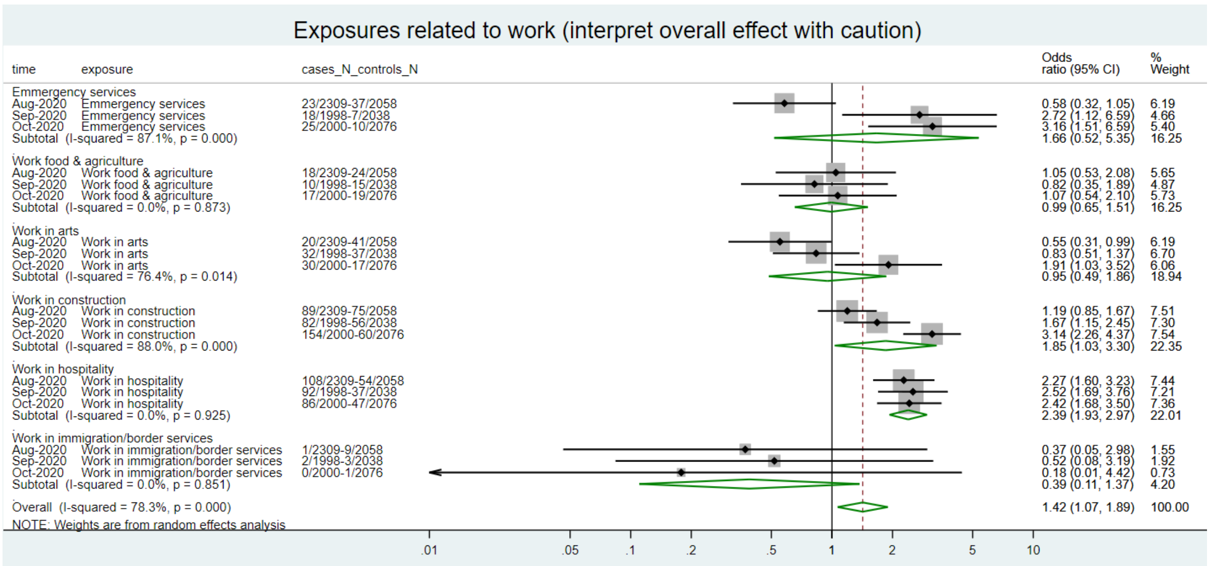
There are indications of transmission between employees in related locations such as a shared apartment, shared bedroom and associated carpool [2, 32]. At risk occupations identified in the international literature are those working in public facing jobs including shop workers, school staff, transport staff and hospitality workers, as well as those working in confined spaces such as abattoir staff, taxi drivers, migrant workers and construction teams.

These occupational factors are closely related to socioeconomic inequalities and underlying vulnerabilities (figure 3), including higher exposure due to working hours, working in low-paid or multiple jobs, and increased risk due to living conditions. For instance, in Canada, social determinants related to housing, education, and recent immigration were associated with increased COVID-19 risks, with little evidence of selection bias [12]. In the US, COVID-19 pandemic disproportionately impacted Latino population, a segment of the workforce that experiences ongoing occupational exposure. In addition to meatpacking plants, most of this community is employed in factories or in other service-based industries [19].

National evidence:
Contact Tracing data (1st July 2020 and 23rd November 2020)
Age standardised case rates infection rate per 100,000 population among 16-64 year olds by sector of employment show significant differences with higher cases seen in those occupations working in food and agriculture (whose main job was in manufacture of food products or beverages) and warehouse (warehousing and support activities for transportation), followed by arts and recreation, social care, hospitality, transport [8].

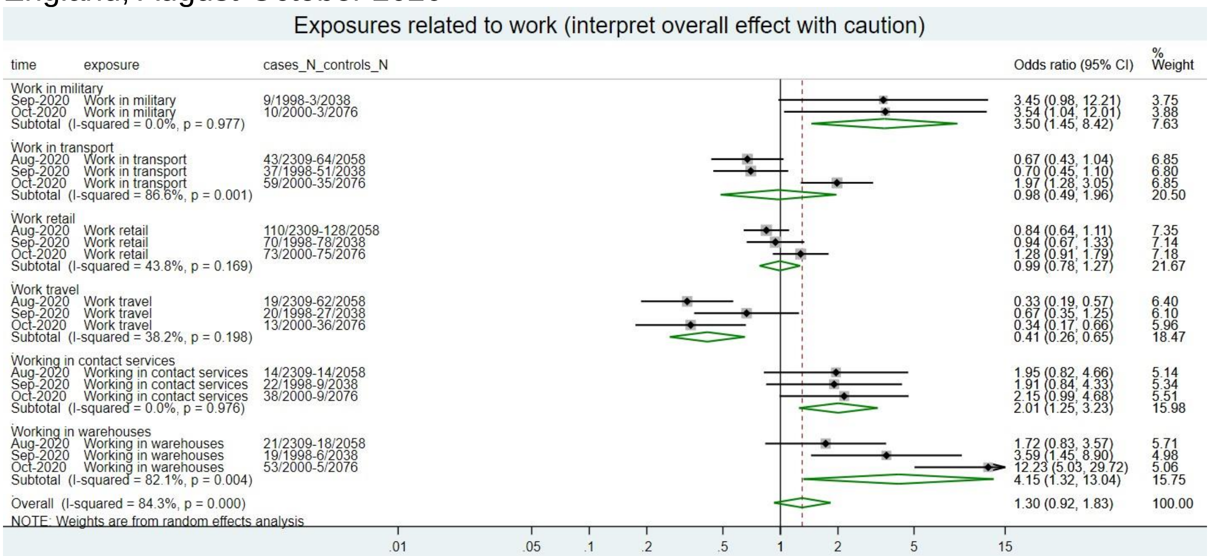
Case control study
The study showed that there was a strong statistical evidence that working in warehouse settings, construction and hospitality, as well as health and social care was associated with increased odds of being a COVID-19 case [8].

Figure 1: Meta-analysis with random effects of COVID-19 exposures related to work places for the three study periods independently and combined by exposure group, England, August-October 2020



- *Working in emergency services: includes fire brigade, ambulance and police.*
- *Work food and agriculture:*
- *Working in arts, or recreation – music, theatre, gyms, cinema, or leisure/sports centres.*
- *Work in construction: includes, labour, office work and manufacturing – textiles, electronics, etc.*
- *Work in hospitality – working in restaurants, food and drink outlets, lodging etc*
- *Excludes healthcare, social care and education*

Figure 2: Meta-analysis with random effects of COVID-19 exposures related to work places for the three study periods, independently and combined by exposure group, England, August-October 2020



- Working in military – including the Navy, Army and Air Force
- Work in transport refers to working in public transport (e.g. underground, trains or buses)
- Work in retail: fashion, food, newsagent, health and beauty, home, sports and leisure, supermarket and technology
- Work travel: includes work related travel; attending conferences, door-to-door sales, visiting clients.
- Working in close contact services – barbers, hairdressers, nail salons, tattoo studios and tanning salons, and
- Working in warehouse settings –warehouse, haulage, distribution etc

ONS Survey

ONS analysis of data between March and June has highlighted that occupations with higher COVID-19 related death rates included health and social care workers, security guards, bus/coach/taxi drivers, construction workers, cleaners, and sales and retail assistants [20]. 72% of these deaths were estimated to result from contracting SARS-CoV-2 before the first lockdown. A previous analysis also indicated that risk was associated with working in environments with high virus exposure, working in close proximity to others, coming into contact with lots of different people [21]. This analysis was adjusted for gender, but not for age, ethnicity or socio-economic status, all of which may have significant influence on mortality. More data and adjusted analysis are needed to understand risk factors associated with mortality independent of the setting.

Interpretation

- Much of the evidence from outbreak investigations and contact tracing relates to workplace settings, while survey data of individuals (e.g ONS) relates to occupations. There would be benefits in correlating these data sets together if possible, as well as in the systematic and consistent collection of occupational data.

- Occupational risk factors are closely related to socioeconomic inequalities and underlying vulnerabilities (figure 3). These risk factors in workplace environments include: settings involving greater social mixing and exposure to multiple contacts, a core industry which can't work from home or shut down even when there are cases, and socio-economic factors including low-paid or zero hours jobs, migrant work forces, shared housing and shared transport (high confidence). Environmental risk factors vary substantially by setting and sector, however those where physical distancing is difficult, face to face or close interaction takes place, ventilation is poor or those that operate in a low temperature indoor environment appear to be higher risk (high confidence).
- Individuals who are working in these occupational environments and at greater risk of exposure and onward transmission (not only due to their occupation but also housing, use of public transport, ability to social distance) may require additional interventions to prevent onward transmission, such as routine testing in high-risk occupations and in neighbourhoods that engage in mobility due to working as well as provision of PPE, supported isolation and housing for isolation (medium confidence).
- In many workplace settings where reported risks are very low, it is difficult to draw firm conclusions about the potential risk as these settings are often those which have had significant closure/work from home over the past 9 months.
- From a programmatic perspective, timely assessments and interventions for infection control and prevention can address the intersection of occupational risk and employment.

2.4 Evidence for transmission in public and private transport

International evidence:
Although travelling together has been cited as a risk factor for transmission, [23] there is limited good evidence to conclusively show how and when transmission occurs in transport settings.

A number of studies have shown transmission on aircraft [24, 25, 26]. The experience from contact tracing in England during the containment phase (February-March 2020) showed that the reporting of symptomatic COVID-19 due to transmission on short to medium haul flights is likely to be low with an observed an attack rate of 0.2% among those whose only known encounter with the index case was on the flight, and 3.8% when further restricting to those who were contact-traced. However this is likely to be an underestimate because of the limited testing undertaken at the time (PHE data under peer review). [38].

A study on train travel in China, suggests risks are highest for those in the same row as the infectious person, and that risk increases with duration of journey [27]. An early analysis of data in Wuhan found significant association between train travel (but not cars or flight) and new COVID-19 cases in other cities; this shows geographic movement, but doesn't confirm whether transmission happened on the transportation. Transmission on buses has been recorded, with analysis in two studies suggesting that airborne transmission may have played a role [28,29].

National Evidence
ONS data early in the pandemic (11th May) indicated that road transport drivers including male taxi and cab drivers and chauffeurs, and bus and coach

drivers had significantly higher rates of death from COVID-19 [31]. However the data suggests transmission could be happening within confined settings of these vehicles and those who are exposed to multiple people may be at higher risk of infection. It should also be noted that this data was prior to the recommendations to wear face coverings and provide enhanced ventilation.

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Interpretation

- Transmission can take place in public and private transport settings, however there is limited evidence that transmission occurring in transport vehicles is contributing to widespread transmission of the virus (medium confidence).
- Risk factors include close proximity, duration of exposure and in some cases poor ventilation (high confidence). Taxis and private cars may pose a particular risk due to the close proximity of people (medium confidence).
- Understanding transmission risks in transport environments is particularly challenging. It is a transient environment where people often spend short periods of time, and with the exception of airplane travel there are usually poor records of travel. Transport vehicles do not have a postcode and hence cannot be accurately recorded within test and trace data.
- Two UKRI studies and the National Core Study on transmission are looking to better understand risks on public transport, however even these studies may not be able to measure transmission directly.

2.5 Gaps in evidence

The evidence to date shows that transmission can occur in all settings. The relative contribution of each setting other than the home is likely to be small. However, some settings may offer greater opportunities to facilitate or reduce transmission than others, and hence may have a greater importance in contributing to regional and national infection rates that their individual risk would suggest. Understanding the transmission between different households is also an important aspect in evaluating how the epidemic progresses; modelling using the concept of an inter-household reproduction number, sometimes called R-star, can help to characterise this [37].

Transmission events in some settings may be more associated with contact patterns and extent of social networks which increase the risk of exposure and onward transmission rather than the setting environment itself; however, this balance is unknown. Further evidence is needed on the impact of mitigation measures on transmission, and the impact that this has on the national infection rates. Some insight may be gained from outbreak investigations as natural experiments.

Both international and UK data suggests that there is a strong association between socioeconomic deprivation and a higher risk of infection. This is especially the case for people working in low paid public facing jobs, who are at greater risk of exposure and onward transmission due to working and living conditions. However, more understanding is needed about the intersection between occupational and household risk. Further analysis of data adjusting for living conditions could enable better understanding of the occupational risk and vice versa.

As a large proportion of cases do not arise among people reported as contacts, it is important to understand what proportion of this is due to under reporting, and what proportion are genuinely unknown contacts. Comparison of contact tracing data with targeted cohort studies such as COMIX or ONS surveys, and specific surveys/focus groups may enable an understanding of the likelihood of how many people are underreporting contacts, who they are, and the reasons why.

Despite its limitations, greater interrogation of contact tracing data may provide valuable insight into likely exposures. Contact tracing data (including backward contact tracing data) can help understand the exposures that those cases have had in the days prior to onset of symptoms / positive test result. Information on common exposures between cases can be used systematically to identify chains of transmission between unknown contacts (work underway through PHE and transmission group). Contact tracing data can also help improve our understanding of how the infection was brought into the home (work underway through PHE and transmission group).

Greater knowledge is needed to understand transmission in settings such as social and leisure environments and public transport where interactions between different social networks are likely, but are very difficult to capture. These are likely to require well designed case-control or cohort studies, although some insight may be possible from analysis of national data sets.

Many of the outbreaks and data that have been published are from the first wave of the pandemic, and often relate to cases before additional mitigation measures have been applied. It will be important to evaluate outbreaks and data from the second wave to understand where mitigations may have been important in reducing transmission and where transmission may have happened regardless of the interventions. This analysis may yield important clues about the mode of transmission however it relies on the analysis and publication of UK and international studies.

Table 1: Strengths and challenges of the approaches to study activities and settings associated with SARS-CoV-2 transmission			
	Strengths	**Challenges**	**Opportunities**
Case series	Hypothesis generation	Descriptive, not analytical Prone to biases	
Outbreak investigations	Natural experiments Real world data, offers a chance to understand what might cause a surge of cases in certain settings Rapid and results often generated quickly Provide narrative for the public that helps understand risk System for identifying and controlling outbreaks exists	Lack of capacity in the system currently to undertake thorough outbreak investigations. Even with increased capacity, data quality is likely to be an issue. Investigations are also heavily affected by the external stakeholders' capacity. Data quality often poor (missing data, often not enough information to do analytical epidemiology) Data comes from different sources and there is no standardisation of testing routes for outbreaks. Analyses often not robust enough as not planned for research purposes, but to inform public health action. Outbreaks not necessarily typical / representative. Might provide a biased view on where transmission is likely to occur as outbreaks may not be consistently reported and ascertainment / reporting bias is likely to exist	To build a mechanism for focused investigations with increased capacity for certain outbreaks which may provide further information on transmission
Test and Trace data	Provides the raw data which can be used for analytical and modelling studies Large dataset of systematically collected information on all cases	<u>Overall:</u> Not designed to understand where transmission occurs. Designed to inform public health action and surveillance <u>Test data</u>: Potential delays at every stage of the process (from seeking a test to getting results and to being contact traced)	

	Rapid identification of links between cases - potential transmission events Data easily available for rapid analyses	There are biases and differences in test uptake. Testing patterns change and evolve constantly Due to challenges with data flows, it is often difficult to ensure high data quality and timely reporting Data quality also varies substantially by reporting laboratory (e.g. for completeness on demographics) <u>Trace data</u>: Completeness of the information provided by cases is often incomplete (both for contacts and exposures reported) Delays in contact tracing (e.g. due to data flows), may also cause recall bias Variation in how effectively identifies certain exposure settings	
Cross sectional studies	Hypothesis generation	Rarely analytical, mainly descriptive Prone to biases	
Case control studies	Timely, can rapidly inform policies Cost-efficient Often used when the outcome is rare	Disincentives exist for cases to provide full information Prone to selection bias (mainly controls) unless study population nested from an existing cohort	Link the existing studies by making changes to existing study designs Case-control study (PHE) could be linked with ONS study or other cohort studies (e.g. recruiting controls from existing cohort studies)
Cohort studies	Less prone to biases. More resources required	Evidence needed more quickly than this approach can generate it. Rare outcome – requires a recruitment of large number of people	
Epidemic Modelling studies	Can provide projections into the near future	Rely on evidence and data generated by other approaches - outputs of models can only be as	

	Can capture the risk frequency and the correlations between risks to support apportionment of cases to settings/factors Can measure intangible processes (e.g. parameters that serve as proxy on behaviour like social mixing) Cost efficient Do not require recruitment of participants or experiments in 'real-life'	good as the input data (see Test and Trace data challenges) Rely heavily on multiple assumptions (which may or may not be accurate) Difficult to understand how transmission is happening as the focus is on population level	
Physical and experimental models (e.g. use of tracers, computational models of environments, QMRA models)	Can provide insights into the physics of how transmission happens Can be used to quantify the theoretical efficacy of some mitigation measures Supports design of engineering and environmental mitigations	Rely heavily on multiple assumptions (which may or may not be accurate) Often built on idealised scenarios that can't incorporate complexity or behavioural aspects Difficult to relate outcomes to population scale effects	Linking models with outbreak investigations or epidemic modelling approaches may give greater insights into transmission routes and the impact of mitigations
Phylogenetic studies	Comparison of viral sequences can confirm transmission patterns. Rapid and can also be used to detect emergence of new clusters.	Overall usefulness depends on associated metadata	
Meta-analyses	Providing evidence synthesis and further evidence on association observed in multiple studies (consistency)	Only able to use studies which have similar methods	Provides comparisons across different countries

Figure 3: Factors that link socioeconomic inequalities to higher risk of infection

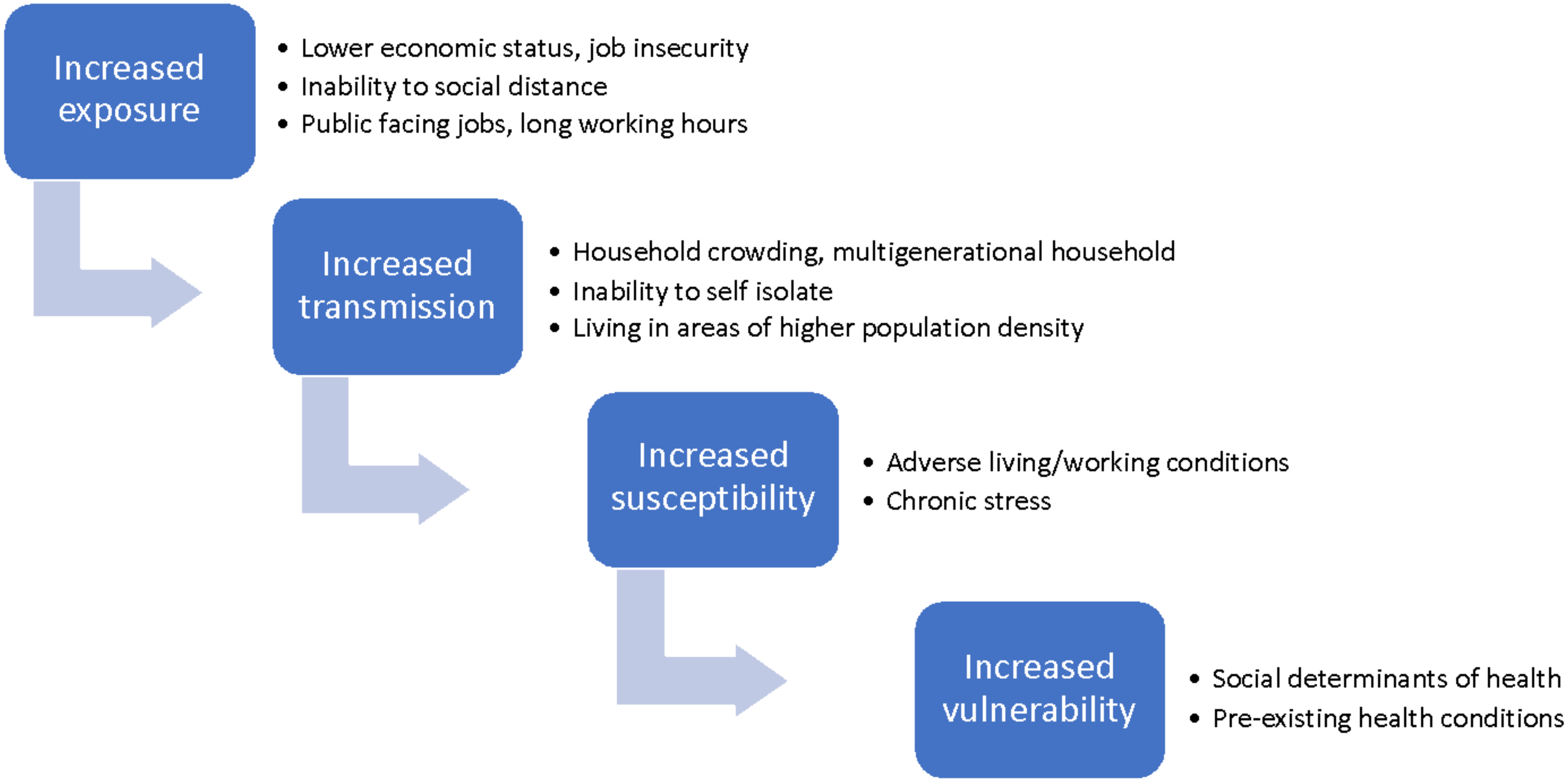

Table 2: Summary of factors associated with risk of transmission (from EMG/Nervtag paper)

Factors associated with risk of transmission	Lowest risk of transmission	Highest risk of transmission
Environmental factors		
Proximity	Always maintain >2m	Regular close interaction < 1m
Duration	A few minutes or less	Several hours
Number of occupants	People spaced out, large space	People closely packed, small space
Shared air and Environmental conditions	Outdoors, well ventilated indoor Normal indoor temperatures, humidity and fresh air	Indoors with poor ventilation, recirculated air Low temperature, low humidity
Viral emission	Passive activity, face coverings	Aerobic activity, singing, loud talking, no face Coverings
Shared surfaces	Rarely touch shared surfaces, good cleaning	Regular touching shared surfaces, infrequent cleaning
Human factors		
Contact frequency	Case isolation, infrequent contact	Daily, regular contact
Networked	Contacts maintained within a small bubble	Shared space with multiple strangers
Hygiene behaviours	Regular hand hygiene, use of face coverings	Poor hand hygiene, no face coverings
Occupational factors	Small network, not public facing	Care/health sector, public facing, long working hours

Socio-economic factors	Work from home, able to isolate	Poverty, crowded housing, inability to isolate for both space and financial reasons

Annex A: Example risk tables

These tables provide a general, high-level evaluation of risk factors in a number of generic settings. They consider the likely ranges of relative risk when common mitigations have been applied. In some cases mitigations that would bring the risk towards the lower end of the range are highlighted. They are designed to give a steer towards the factors that should be considered when assessing risks - the actual risk will be setting specific.

Example 1: Risk factors in a household setting	
Environmental factors	
Proximity	*Higher risk*. Household members have close interaction with each other, especially between partners and children. Proximity of visitors will depend on the size of the space. Familiarity with friends/family may cause people to get closer than in other settings.
Duration	*Much higher risk*. Household members spend significant periods of time in the same shared space.
Number of occupants	*Risk factor may vary substantially*. This will depend on the size of home and number of people. Larger households are associated with a higher risk. Shared bedrooms are recognised as higher risk of infection. Houses of multiple occupation and multi-generational homes may pose a higher risk
Shared air and Environmental conditions	*Higher risk*. Indoor setting where ventilation can be variable. Many homes have low ventilation rates and increasing ventilation often relies on human behaviour to open windows. Most homes can maintain reasonable temperatures and humidity, however the poorest or those in poorly ventilated homes may struggle to heat their homes adequately, especially while also increasing ventilation which could increase risk of infection.
Viral emission	*Moderate to higher risk*. Activities are generally passive (breathing/talking) which doesn't enhance aerosol generation, however face coverings which reduce viral emissions are rarely applied in households.
Shared surfaces	*Higher risk*. Multiple shared surfaces including kitchens, bathrooms and interactions while dining or during family activities. Risk can be difficult to manage with visitors, particularly in smaller environments.
Human factors	
Contact frequency	*Higher risk*. Daily regular contact with household members, although contact with others in a home setting may be lower.
Networked	*Risk factor may vary substantially*. The household network is likely to be small, but the networks that members interact with could be very variable depending on the age profile, work, social network and location.
Hygiene behaviours	*Higher risk*. Will vary between households, however people are more likely to be more complacent about hygiene within their own environment rather than in settings that are shared with strangers.
Occupational factors	*Risk factor may vary substantially*. Will vary significantly from a very low risk for those who are retired or working in settings with low interaction, to a high risk for those working in occupations which have a higher probability of contact with a covid-19 case, and mitigation is poor or ineffective.

Socio-economic factors	_Risk factor may vary substantially_. Will vary significantly from a very low risk for those who can work from home and are financially secure, to a high risk for those who are in crowded housing and have financial situations which restrict their ability to isolate or lead to higher contact networks through multiple jobs and social connections.

Example 2: Risk factors in a Pub/Bar	
Environmental	
Proximity	_Moderate to higher risk._ As venues for socialising, the level of proximity is higher than average, particularly among groups where "rule of 6" could enable close interactions between members of different households. The degree of proximity is highly dependent on the arrangements in place. The degree of contact between groups can be reduced through table service only rules and measures such as screens/markers being applied to enable distancing.
Duration	_Higher risk_. The duration is typically greater than 15 min but could vary from under an hour to several hours.
Number of occupants	_Risk varies substantially_. Depends on the location and size of the venue. Higher numbers of people increase the probability of infectors, increase the number who can become infected and are more likely to result in closer proximity and increased use of shared surfaces and air. Restriction of numbers to manage social distancing is being applied and should consider facilities such as toilets as well as the main venue.
Shared air and Environmental Conditions	_Risk may vary substantially_. This varies depending on the design of fresh air ventilation. Many venues rely on natural ventilation and some have limited fresh air supply and use local air conditioners for comfort. Maintaining a comfortable temperature and humidity is generally feasible, but may pose challenges in cold weather. Potential for use of air cleaners in poorly ventilated spaces. Venues with outdoor space may have lower risks, but care needs to be taken to ensure outdoor enclosures don't create a surrogate indoor space.
Viral emission	_Moderate to higher risk_. Activities are generally passive (breathing/talking), however in crowded venues, or with loud background music, shouting may be common which may enhance aerosol generation. Face mask use is not easily compatible with eating and drinking.
Shared surfaces	_Higher risk._ Potential for increased risk through shared tables, seat backs, counters, toilets and possibly passing around of glasses and cutlery etc. Can be reduced through table service and regular cleaning, especially in toilets.
Human	
Contact frequency	_Risk may vary substantially_. Higher risk for the staff, and those visiting frequently, compared to an individual who visits these settings rarely. This may vary with age, geographic location, amount of alcohol consumed and type of venue.
Networked	_Moderate to higher risk_. Traditionally some venues are designed for high frequency social contact. There may be extensive moving between venues on the night scene. However some venues are focussed more on serving a regular local clientele.

Hygiene behaviours	*Moderate to higher risk*. Provision of hand washing/sanitizer can be achieved, but adherence may vary significantly between customers and settings. Face coverings are rarely worn.
Occupational factors	*Risk factor may vary substantially*. Public facing, often with shared facilities. The venues may be a high risk setting for elderly staff or those with co-morbidities to work.
Socio-economic factors	*Risk factor may vary substantially*. Will depend significantly on the setting, location and staffing. For instance, bar staff may often be on zero hours contracts, and therefore may not be able to self isolate as otherwise could lose income. In some locations staff have more than one job and may be living in houses of multiple occupancy. Supported isolation/quarantine and income relief could improve people's ability to follow isolation guidelines.

Example 3: Risk factors in a supermarket	
Environmental	
Proximity	*Lower risk*. Most supermarkets can manage the occupancy to ensure that the environment is not crowded. Close proximity (<2m) is typically fleeting and it is unlikely that people will be in close proximity for any significant period of time. Screens and markers are widely used to support distancing
Duration	*Lower to moderate risk*. Visits to supermarkets are typically under 1 hour. Events like Christmas may pose a higher risk if people are shopping for larger groups over a longer period of time, and high volumes of shoppers increase qeuing times both inside and outside the store.
Number of occupants	*Lower to moderate risk*. This will depend on the size and number of people, however even smaller stores are usually able to manage the number of people inside at any time by using door staff or other access control approaches. Larger stores may have a high number of people, but the space means they are well spaced out.
Shared air and Environmental conditions	*Risk may vary substantially*. Larger stores tend to be well ventilated and the large volume provides dilution. Small corner shop type stores may rely on natural ventilation- risk may be increased if no window or door open. Most stores are able to manage indoor temperatures and humidity well, however chilled/frozen food cabinets could harbour any virus on surfaces for longer than expected.
Viral emission	*Lower risk*. Activities are generally passive (breathing/talking) which doesn't enhance aerosol generation, face coverings are widely applied although compliance can be variable.
Shared surfaces	*Higher risk*. Surfaces including trollies/baskets, freezer cabinets, checkout belt/payment. Most goods are not handled by multiple people. Risks can be managed well using cleaning and hand hygiene. Risks in chilled food areas should be explicitly considered especially for staff.
Human factors	
Contact frequency	*Risk factor may vary substantially*. This would be higher risk for the staff working in the setting, and those using the setting frequently, compared to an individual who visits these settings rarely.

Networked	*Risk factor may vary substantially*. It will depend on the extent of the social network of the individual visiting the setting including age profile, work, social network and location. Visited by all groups in society, including those in higher risk occupations, however little direct interactions.
Hygiene behaviours	*Lower to moderate risk*. Would be higher without mitigations, however sanitizers and cleaning for trollies/baskets are widely provided and use of face coverings supports respiratory hygiene and reduces face touching.
Occupational factors	*Risk factor may vary substantially*. Will vary significantly depending on the workforce and who is entering the store. Some stores may have higher proportion of customers from high risk occupations.
Socioeconomic factors	*Risk factor may vary substantially*. Will depend on the location of the store and the demographics of the area where it is located.

Example 4: Risk factors on public transport (bus/train/tram/tube)	
Environmental	
Proximity	*Risk may vary substantially*. Will depend on the mode of transport and the number of people travelling. Quiet journeys will be easy to distance however crowded journeys are very likely to result in interaction at <2m.
Duration	*Risk may vary substantially*. Can range from a 10 min bus/tram/tube journey through to several hours on an intercity train.
Number of occupants	*Risk may vary substantially*. Will depend on the mode of transport and the number of people travelling.
Shared air and Environmental conditions	*Risk may vary substantially*. Most transport vehicles are well ventilated; however it varies between the mode of transport and the particular design of vehicle. Temperature and humidity will depend on the mode of transport. Generally well controlled on trains, and temperatures on tubes are high. However buses and commuter trains could vary.
Viral emission	*Lower risk*. Activities are generally passive (breathing/talking) which doesn't enhance aerosol generation, face coverings are widely applied although compliance can be variable.
Shared surfaces	*Risk may vary substantially*. Surfaces including grab handles, ticket barriers and surfaces around seating. Contact with surfaces will depend on the mode of transport and design of infrastructure. May increase on busy services as people hold onto rails when standing .
Human factors	
Contact frequency	*Risk factor may vary substantially*. This would be higher risk for the staff working within the passenger carriages, and those using the setting frequently, compared to an individual who visits these settings rarely .
Networked	*Risk factor may vary substantially*. It will depend on the extent of the social network of the individual visiting the setting including age profile, work, social network and location. Visited by all groups in society, including those in higher risk occupations, however little direct interactions .

Hygiene behaviours	_Moderate risk_. Use of face coverings supports respiratory hygiene and reduces face touching, good cleaning mitigations applied by most operators. Hand hygiene at stations but more challenging when on transport
Occupational factors	_Risk factor may vary substantially_. Will vary significantly depending on the customer base. Some routes may have higher proportion of customers from high risk occupations.
Socio-economic factors	_Risk factor may vary substantially_. Will depend on the location and the demographics of the area, some routes may serve more deprived areas. Those working in these sectors are identified as high risk for infection and mortality. Provision of PPE, supported isolation and quarantine, routine testing in at risk occupations could provide additional layer of mitigation.

Example 5: Risk factors in a gym	
Environmental	
Proximity	_Lower risk_. Mitigations in most gyms have ensured that people can normally stay 2m apart, with spaces that are more crowded such as reception areas/toilets with managed occupancy and requiring face coverings.
Duration	_Moderate to higher risk_. People will typically spend 30-90 minutes in a gym
Number of occupants	*Moderate to higher risk*. This will depend on the size and number of people, however most are managing the number of people inside at any time. Risks are likely to be higher in group exercise classes. More people increases the probability of an infector and the number of people who can become infected.
Shared air and Environmental conditions	_Risk may vary substantially_. Some spaces are well ventilated however smaller locations that rely on natural ventilation may have increased risks if no windows or doors are open. Ventilation rates need to be higher than in other settings to deal with risk of enhanced aerosols Most gyms are able to manage indoor temperatures and humidity well, are unlikely to see extreme conditions.
Viral emission	*Much higher risk*. High aerobic activities may enhance aerosol generation, and deeper breathing may increase exposure. Low intensity activities (yoga, climbing) will be moderate risk. Face coverings are rarely worn in most settings, especially where activities are higher intensity.
Shared surfaces	_Higher risk_. Surfaces such as gym equipment are touched by multiple people and involve high contact area (whole hand, not just one finger). Risks can be managed using cleaning and hand hygiene, but this needs very clear protocols.
Human factors	
Contact frequency	_Risk factor may vary substantially_. This would be higher risk for the staff working in the setting, and those using the setting frequently, compared to an individual who visits these settings rarely.
Networked	_Risk factor may vary substantially_. It will depend on the extend of the social network of the individual visiting the setting including age profile,

	work, social network and location. Visited by several groups in society, including those in higher risk occupations.
Hygiene behaviours	*Moderate to higher risk*. Many provide mitigations such as hand sanitizer and have protocols for use and for cleaning. However this may be compromised by individual compliance
Occupational factors	*Risk factor may vary substantially*. Will vary significantly depending on who is using the facility. Some gyms may have higher proportion of customers from high risk occupations.
Socioeconomic factors	*Risk factor may vary substantially*. Will depend on the location of the gym and the demographics of the area where it is located

Example 6: Risk factors in a communal multi-occupancy shared sleeping airspaces - including night shelter/severe weather emergency provision (SWEP) **Issues are similar for some migrants in communal accommodation but there are also important differences so this will be covered in a separate risk assessment**	
Environmental factors	
Proximity	<u>*Higher risk*</u>. Depending on space available there may be insufficient space to ensure beds/sleeping mats are sufficiently distanced. Residents and staff may need to come into close proximity in corridors and queueing for toilets. Many facilities run on "1st come 1st served" during cold weather leading to "competitive" queueing.
Duration	<u>*Much higher risk*</u>. The duration is minimum of 12 hours (overnight and includes early evening), time may be spent in a shared bedroom.
Number of occupants	<u>*Higher risk*</u>. High unmet need for accommodation such that capacity of accommodation does not meet need leading to high risk of densely occupied facilities, particularly during cold weather periods. Occupancy varies significantly with potential for > 50 people sharing the same airspace overnight.
Shared air and Environmental conditions	<u>*Higher risk*</u>. Facilities are usually one single room/shared air space for overnight use. The buildings are not purpose built for accommodation. During cold weather periods it may be challenging to maintain high levels of ventilation and venues need to be kept warm as people are coming in to escape the cold
Viral emission	<u>*Moderate to higher risk*</u>. Studies have demonstrated up to 50% of homeless people have chronic cough. Loud snoring is common and may contribute to aerosolization. Not practical to wear face masks overnight. Poor access to testing and low uptake will lead to late diagnosis. Symptoms may be masked by chronic cough and fever-like symptoms related to substance use.
Shared surfaces	<u>*Higher risk*</u>. Bathrooms shared with many others. Door handles -frequent entering and exiting to smoke outside. Tables set up for early evening meals and breakfast.
Human factors	
Contact frequency	<u>*Higher risk*</u>. High contact rate within the facility. Used nightly during periods of cold weather.
Networked	<u>*Higher risk*</u>. Likely to be high turnover of residents and staff. Residents will mainly be unknown to each other. Extensive contact networks outside of facilities through substance use networks, illicit economic activities and day centres.
Hygiene behaviours	<u>*Higher risk*</u>. Basic shared toilet and bathroom facilities. Challenging behaviour may limit compliance with all recommended IPC measures.
Occupational factors	<u>*Higher risk*</u>. Faith based organisations often reliant on post retirement age staff including some at extreme clinical risk. Staff also need to stay

	overnight for 12 hour shifts. Potential for exchange of staff between shelters. Staff share same airspace with residents and often do not have an office/staff area.
Socio-economic factors	*Higher risk*. High level of destitution/migration/exploitation as cheap labour. Unable follow guidance for self-isolation due to lack of own accommodation. Accommodation support, supported isolation and quarantine, provision of PPE could provide additional layer of mitigation in this population.

References:

1. EMG. Transmission of SARS-CoV-2 and Mitigating Measures - update, 4 June 2020. Available at: https://www.gov.uk/government/publications/transmission-of-sars-cov-2-and-mitigating-measures-update-4-june-2020.

2. NERVTAG/EMG. SARS-COV-2 Transmission Routes and Environments, 22 October 2020. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/933225/S0824_SARS-CoV-2_Transmission_routes_and_environments.pdf
3. Cevik M, Tate M, Lloyd O, Maraolo AE, Schafers J, Ho A. SARS-CoV-2, SARS-CoV, and MERS-CoV viral load dynamics, duration of viral shedding, and infectiousness: a systematic review and meta-analysis. The Lancet Microbe Nov 2020. doi: https://doi.org/10.1016/S2666-5247(20)30172-5
4. Sun K, Wang W, Gao L, et al. Transmission heterogeneities, kinetics, and controllability of SARS-CoV-2. Science **2020**: eabe2424. doi: https://doi.org/10.1126/science.abe2424
5. A Hayward AaB, S and Johnson, AM and Fragaszy, EB Public activities preceding the onset of acute respiratory infection syndromes in adults in England - implications for the use of social distancing to control pandemic respiratory infections. [version 1; peer review: 2 approved]. *Wellcome Open Res* 2020, **5**:54 doi: https://doi.org/10.12688/wellcomeopenres.15795.1

6. Cevik M, Marcus JL, Buckee C, Smith TC. SARS-CoV-2 transmission dynamics should inform policy [published online ahead of print, 2020 Sep 23]. *Clin Infect Dis*. 2020;ciaa1442. doi:10.1093/cid/ciaa1442
7. ECDC. Transmission of COVID-19. Available at: https://www.ecdc.europa.eu/en/covid-19/latest-evidence/transmission Accessed November 25.
8. Hiironen, I, Saavedra-Campos, M, Panitz, J, Ma, T, Nsonwu, O, Charlett, A, Hughes, G, Oliver, I, Occupational exposures associated with being a COVID-19 case; evidence from three case-controls studies, PHE 2020 [Manuscript submitted for preprint at time of publication].

9. Tommaso Celeste Bulfone, MS, Mohsen Malekinejad, MD, DrPh, George W Rutherford, MD, AM, Nooshin Razani, MD, MPH, Outdoor Transmission of SARS-CoV-2 and Other Respiratory Viruses, a Systematic Review, *The Journal of Infectious Diseases*, 2020 https://doi.org/10.1093/infdis/jiaa742

10. Weed M, Foad A, Rapid Scoping Review of Evidence of Outdoor Transmission of Covid-19, MedRxiv preprint, September 2020, https://doi.org/10.1101/2020.09.04.20188417

11. Koh WC, Naing L, Chaw L, Rosledzana MA, Alikhan MF, Jamaludin SA, et al. What do we know about SARS-CoV-2 transmission? A systematic review and meta-analysis of the secondary attack rate and associated risk factors. PloS one. 2020;15(10):e0240205.

12. Sundaram ME, Calzavara A, Mishra S, Kustra R, Chan AK, Hamilton MA, Djebli M, Rosella LC, Watson T, Chen H, Chen B, Baral SD, Kwong JC, The Individual and Social Determinants of COVID-19 in Ontario, Canada: A Population-Wide Study, medRxiv [preprint], 2020.11.09.20223792; doi: https://doi.org/10.1101/2020.11.09.20223792

13. Qifang B, Lessler J, Eckerle I, Lauer SA, Kaiser L, Vuilleumier N, Cummings DAT, Flahault A, Petrovic D, Geussous I, Stringhini S, Azman AS, For the SEROCov-Pop Study Group. Household Transmission of SARS-COV-2: Insights from a Population-based Serological Survey, MedRxiv [preprint], 2020.11.04.20225573; doi: https://doi.org/10.1101/2020.11.04.2022557

14. Dupraz J, Butty A, Duperrex O, Estoppey S, Faivre V, Thabard J, Zuppinger C, Greub G, Pantaleo G, Pasquier J, Rousson V, Egger M, Steiner-Dubuis A, Vassaux S, Masserey E, Bochud M, Nusslé SG, D'Acremont V, Prevalence of SARS-CoV-2 in household members and other close contacts of COVID-19 cases: a serologic study in canton of Vaud, Switzerland, medRxiv [preprint], 2020.11.27.20239244; doi: https://doi.org/10.1101/2020.11.27.20239244

15. Ng OT, Marimuthu K, Koh V, Pang J, Linn KZ, Sun J, et al. SARS-CoV-2 seroprevalence and transmission risk factors among high-risk close contacts: a retrospective cohort study. The Lancet Infectious Diseases. 2020 doi: https://doi.org/10.1016/S1473-3099(20)30833-1

16. Imperial REACT-1 Round 7 Interim Report. Available at : https://www.imperial.ac.uk/media/imperial-college/institute-of-global-health-innovation/imperial_react1_r7_interim.pdf

17. Haug, N., Geyrhofer, L., Londei, A. *et al.* Ranking the effectiveness of worldwide COVID-19 government interventions. *Nat Hum Behav* (2020). doi: https://doi.org/10.1038/s41562-020-01009-0

18. Murti M, Anchonu A, Smith BT, Brown KA, Kim JH, Johnson J, Ravindran S, Buchan SA, COVID-19 Workplace Outbreaks by Industry Sector and their Associated Household Transmission, Ontario, Canada, January – June, 2020 medRxiv [preprint] 2020.11.25.20239038; doi: https://doi.org/10.1101/2020.11.25.20239038

19. Rodriguez-Diaz CE, Guilamo-Ramos V, Mena L, Hall E, Honermann B, Crowley JS, Baral S, Prado GJ, Marzan-Rodriguez M, Beyrer C, Sullivan PS, Millett GA, Risk for COVID-19 infection and death among Latinos in the United States: examining heterogeneity in transmission dynamics, Annals of Epidemiology 2020 doi: https://doi.org/10.1016/j.annepidem.2020.07.007

20. ONS - Coronavirus (COVID-19) related deaths by occupation, before and during lockdown, England and Wales: deaths registered between 9 March and 30 June 2020. Available at: https://www.ons.gov.uk/releases/coronaviruscovid19relateddeathsbyoccupationenglandandwalesbeforeandduringthelockdown

21. ONS - Which occupations have the highest potential exposure to the coronavirus (COVID-19)? Available at:

https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/whichoccupationshavethehighestpotentialexposuretothecoronaviruscovid19/2020-05-11

22. COVID-19 clusters and outbreaks in occupational settings in the EU/EEA and the UK. August 11, 2020. Available at:

https://www.ecdc.europa.eu/en/publications-data/covid-19-clusters-and-outbreaks-occupational-settings-eueea-and-uk

23. Bi Q, Wu Y, Mei S, et al. Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study. The Lancet Infectious Diseases. April 2020. doi: https://doi.org/10.1016/S1473-3099(20)30287-5

24. Bae, S. H.; Shin, H.; Koo, H.-Y.; Lee, S. W.; Yang, J. M.; Yon, D. K., Asymptomatic Transmission of SARS-CoV-2 on Evacuation Flight. Emerging Infectious Disease journal 2020, 26 (11). https://dx.doi.org/10.3201/eid2611.203353

25. Choi, E.; Chu, D. K. W.; Cheng, P. K. C.; Tsang, D. N. C.; Peiris, M.; Bausch, D.; Poon, L. L. M.; WatsonJones, D., In-Flight Transmission of Severe Acute Respiratory Syndrome Coronavirus 2. Emerging Infectious Disease journal 2020, 26 (11) https://dx.doi.org/10.3201/eid2611.203254

26. Hoehl, S.; Karaca, O.; Kohmer, N.; Westhaus, S.; Graf, J.; Goetsch, U.; Ciesek, S., Assessment of SARS-CoV-2 Transmission on an International Flight and Among a Tourist Group. JAMA Network Open 2020, 3 (8), e2018044-e2018044 doi: https://dx.doi.org/10.1001%2Fjamanetworkopen.2020.18044

27. Hu, M.; Lin, H.; Wang, J.; Xu, C.; Tatem, A. J.; Meng, B.; Zhang, X.; Liu, Y.; Wang, P.; Wu, G.; Xie, H.; Lai, S., The risk of COVID-19 transmission in train passengers: an epidemiological and modelling study. Clinical Infectious Diseases 2020 doi: https://doi.org/10.1093/cid/ciaa1057

28. Shen Y, Li C, Dong H, et al. Community Outbreak Investigation of SARS-CoV-2 Transmission Among Bus Riders in Eastern China. *JAMA Intern Med.* Published online September 01, 2020. doi:10.1001/jamainternmed.2020.5225

29. Kaiwei Luo, Zhao Lei, Zheng Hai, Shanliang Xiao, Jia Rui, Hao Yang, Xinping Jing, Hui Wang, Zhengshen Xie, Ping Luo, Wanying Li, Qiao Li, Huilu Tan, Zicheng Xu, Yang Yang, Shixiong Hu, Tianmu Chen, Transmission of SARS-CoV-2 in Public Transportation Vehicles: A Case Study in Hunan Province, China, *Open Forum Infectious Diseases*, Volume 7, Issue 10, October 2020, ofaa430, https://doi.org/10.1093/ofid/ofaa430

30. UCL Virus Watch - Virus Watch preliminary findings on 22nd November 2020. Available at: https://ucl-virus-watch.net/?page_id=913

31. ONS - Coronavirus (Covid-19) Roundup, 11-15 May 2020. Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/articles/coronaviruscovid19roundup11to15may2020/2020-05-15

32. Guenther T, Czech-Sioli, Manja, Indenbirken, Daniela, Robitailles, Alexis, Tenhaken, Peter, Exner, Martin, Ottinger, Matthias, Fischer, Nicole, Grundhoff, Adam, Brinkmann, Melanie, Investigation of a superspreading event preceding the largest meat processing plant-related SARS-Coronavirus 2 outbreak in Germany. SSRN 2020. doi: https://dx.doi.org/10.2139/ssrn.3654517

33. “Prevalence of covid-19 in different occupational groups. Confirmed covid-19 cases in Sweden March 13 - May 27, 2020” [Google translate, in Swedish] https://www.folkhalsomyndigheten.se/contentassets/5e248b82cc284971a1c5fd922e7770f8/forekomst-covid-19-olika-yrkesgrupper.pdf&sa=D&ust=1606943154400000&usg=AOvVaw3oGbLbI6brv4N2ZKEli-mt

34. Cheng H-Y, Jian S-W, Liu D-P, et al. Contact Tracing Assessment of COVID-19 Transmission Dynamics in Taiwan and Risk at Different Exposure Periods Before and After Symptom Onset. JAMA Internal Medicine 2020.

35. Lopez Bernal J, Panagiotopoulos N, Byers C, et al. Transmission dynamics of COVID-19 in household and community settings in the United Kingdom. medRxiv 2020: 2020.08.19.20177188.

36. Springborn, M., Chowell, G., MacLachlan, M. et al. Accounting for behavioral responses during a flu epidemic using home television viewing. BMC Infect Dis 15, 21 (2015). https://doi.org/10.1186/s12879-014-0691-0

37. Black, A.J, House, T., Keeling, M.J., Ross, J.V., The effect of clumped population structure on the variability of spreading dynamics, Journal of Theoretical Biology, Volume 359, 2014, Pages 45-53, ISSN 0022-5193, https://doi.org/10.1016/j.jtbi.2014.05.042.

38. Blomquist, P, Bolt, H, Packer, S., Gobin, M, Oliver, I., Risk of symptomatic COVID-19 due to aircraft transmission: a retrospective cohort study of contact-traced flights during England's containment phase, Influenza and Other Respiratory Viruses [pending publication]