SARS-COV-2 TRANSMISSION ROUTES AND ENVIRONMENTS
SAGE – 22 OCTOBER 2020

Executive summary:

- Evidence continues to indicate the SARS-CoV-2 can be transmitted by three main routes: close-range respiratory droplets and aerosols, longer range respiratory aerosols, and direct contact with surfaces contaminated with virus. Close-range transmission is likely to be the most significant, but there is not yet sufficient evidence to confidently separate out the relative importance of these routes or how they vary between settings (medium confidence).

- Transmission of SARS-CoV-2 is strongly associated with proximity and duration of contact in indoor environments (high confidence). It is possible for SARS-CoV-2 to be transmitted at distances of more than 2 metres (medium confidence). Evidence suggests transmission is most likely when an infectious person is present in the environment or very shortly afterwards. There is good evidence that the virus can survive in environments for long periods, however there is little epidemiological evidence of transmission from residual virus in an environment several hours later (medium confidence).

- A wide range of social, residential and workplace settings have been associated with transmission. The highest risks of transmission, including those from super-spreading events, are associated with poorly ventilated and crowded indoor settings with increased likelihood of aerosol emission (such as loud singing/speech, aerobic activity) and no face coverings are worn such as bars, nightclubs, parties/family gatherings, indoor dining, gyms and exercise classes, choirs and churches (high confidence).

- Evidence continues to suggest that super-spreading events may play a very important role in the epidemic. Estimates suggest that fewer than 20% of infections lead to approximately 80% of secondary cases. Identifying and mitigating those settings where multiple risk factors come together, and large outbreaks are likely to occur should be an important focus in controlling the epidemic (high confidence). Backwards contact tracing (an outbreak investigation approach that aims to trace new cases and their contacts back to the event or place where they originally got infected) is an essential tool for identifying the setting of the transmission and the index case(s) of a cluster that could be linked to other cases. Routine use of this approach will provide valuable evidence on the characteristics of important transmission settings.

- In the same household, frequent prolonged daily contact with the index case, such as dining in close proximity or sleeping in the same room, have been associated with increased transmission (medium confidence).

- The greatest viral load, and thus infectiousness, is observed during the first week of symptoms (especially day 0-5), declining after that. Pre symptomatic and asymptomatic transmission occurs and may play a significant role in facilitating transmission (medium confidence). Effective and rapid contact tracing and quarantine of contacts is therefore essential to identify and isolate contacts with no symptoms before they can spread the infection (high confidence).

- The COVID19 pandemic is strongly shaped by structural inequalities that drive household and occupational risks, such as prolonged working hours in close proximity to others and/or in high risk occupations, use of public transport, and household crowding. It is essential to tailor effective control and recovery measures to the greater needs and vulnerabilities of disadvantaged communities (high confidence).

Part 1: Principles of transmission and risk factors

Summary of factors associated with transmission
Evidence to date suggests transmission risk depends on several factors, including contact pattern (duration of contact, size of gathering/meeting, proximity, activity), environment (outdoor, indoor, ventilation), host-related infectivity/susceptibility pattern (i.e. viral load in relation to disease course, severity of illness, age).

These dynamics are greatly influenced by socioeconomic factors (i.e. crowded housing, job insecurity, poverty). Socio-economic factors act on all other factors and are mechanistically related to contact pattern, host-related factosr and environment. Principles of transmission and key risk factors have been detailed in previous EMG and NERVTAG papers [1]. Risk factors associated with transmission and their Intersection are summarised here in Table 1 and Figure 1. **The highest risks occur when multiple risk factors exist together.**

Figure 1: Intersection of factors associated with risk of transmission

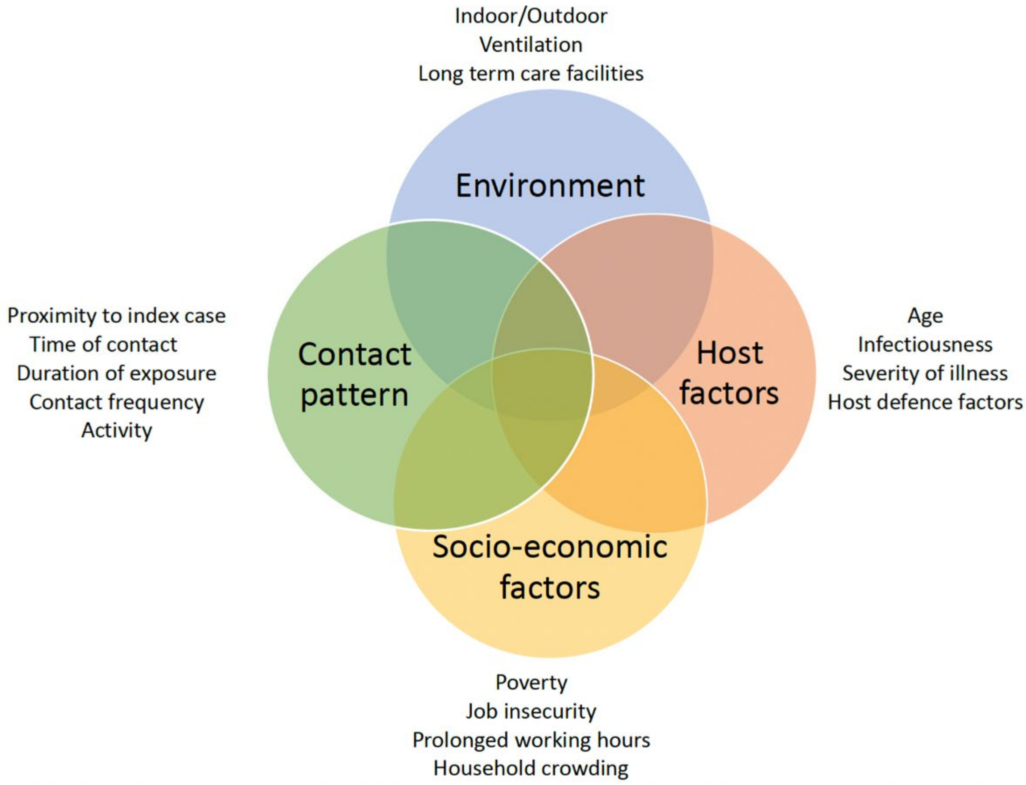


Table 1: Summary of factors associated with risk of transmission

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
Occupant density	People spaced out, large space	People closely packed, small space
Shared air	Outdoors, well ventilated indoor	Indoors with poor ventilation, recirculated air
Environmental conditions	Normal indoor temperatures, humidity and fresh 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

1.1 Transmission routes

Transmission routes have been set out in previous EMG papers. These transmission routes all interact with each other, as illustrated in Figure 2. Environments and activities which enhance any of these routes increase risks, and mitigation measures need to address all three routes of transmission simultaneously.
In summary the three main routes are:

Close-range direct person-to-person transmission when someone is directly exposed to respiratory droplets and aerosols emitted by another person at <2m. These virus carrying particles can lead to virus entering the body through eyes, nasal membranes, oral mucosa, or the respiratory system via inhalation or deposition.
Indirect surface contact transmission happens when someone touches a surface that has been contaminated with the virus. They may then become infected when they touch their nose, eyes or mouth with a contaminated hand or object (fomite). Surfaces can be contaminated through the deposition of respiratory droplets and by people who are infectious touching surfaces with their hands.
Airborne transmission occurs when small virus-containing respiratory aerosols are carried by the air and subsequently inhaled. These aerosols may be released from respiratory actions (breathing, talking, coughing etc), as well as through aerosol generating procedures in a hospital or dental environment. Airborne transmission is associated with infection beyond 2m in poorly ventilated rooms.

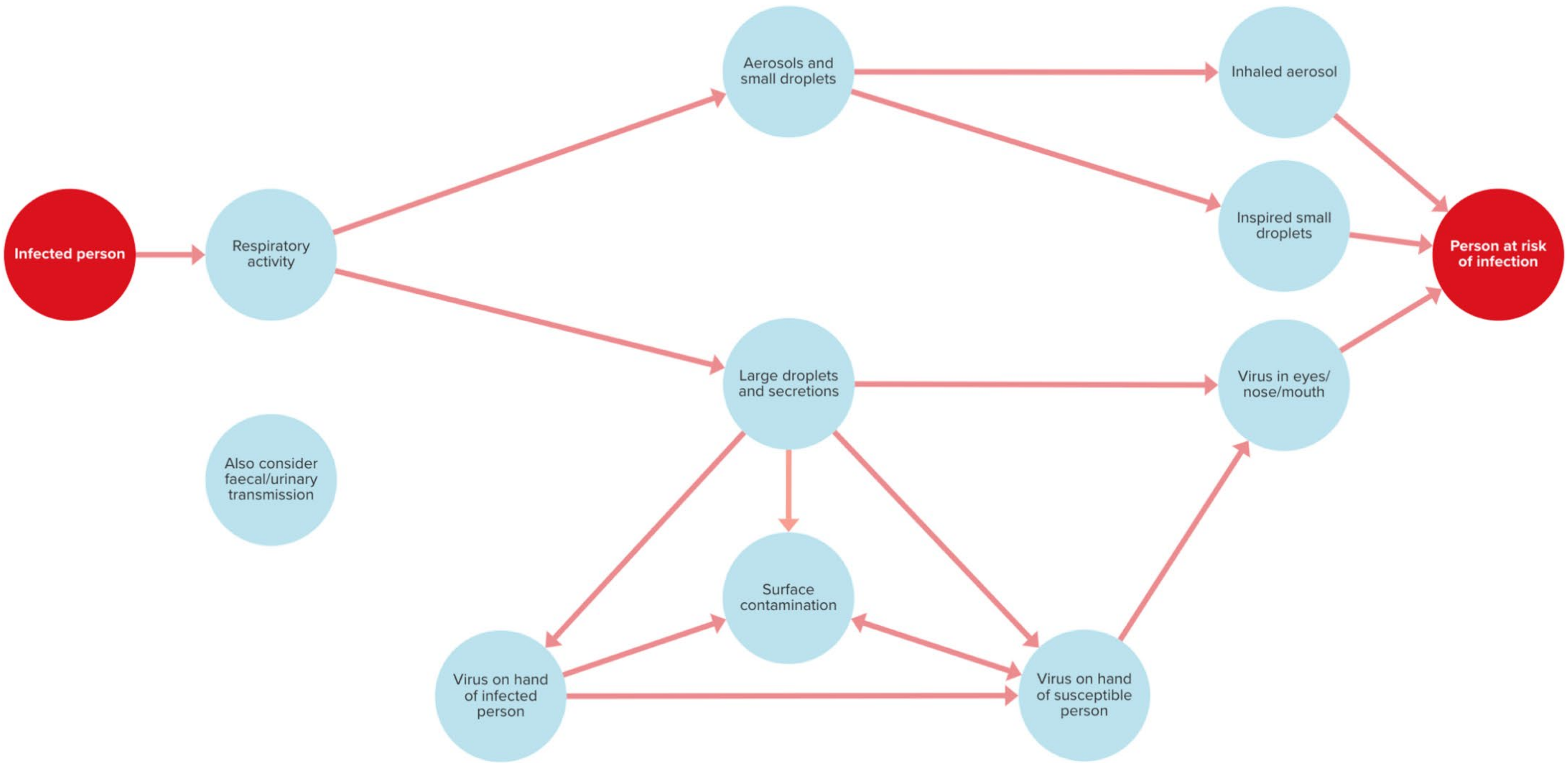
1.2 Approaches to understanding transmission

Understanding where transmission takes place and the modes of transmission is a very challenging task. Data from contact tracing provides initial clues as to the environments where people spend time, but does not give definitive information on where, when and how transmission occurred. Understanding this requires data from multiple approaches including outbreak investigations, case control studies, surveillance studies, intervention studies, laboratory studies and modelling. Evidence may be skewed towards settings where data is available; it is more difficult to measure in settings (e.g. public spaces) where contact tracing is very limited.

It is important to recognise that a setting that appears to have caused 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.

Despite the challenges with providing conclusive evidence there is growing evidence that settings that facilitate the risk factors in table 1 are higher risk, and it is critical that actions are taken in a timely manner based on emerging data and these known risk factors

Figure 2: Illustrative map of main transmission routes for SARS-CoV-2



Part 2: Evidence Summary

2.1 Transmission heterogeneity

Contact tracing and outbreak investigations suggest that many people infected with SARS-CoV-2 do not contribute to onward transmission, and a large number of secondary cases are often caused by a small number of infected patients. Several modelling, contact tracing and phylodynamic studies estimated that approximately 20% of infections caused 80% of secondary transmissions [2-5]. A systematic review of transmission clusters found that most occurred indoors [5], and environmental and host factors such as differences in infectiousness strongly influence this variation. Hallmarks for superspreading events include a combination of factors, typically a highly infectious individual(s) gathered with a large number of individuals in enclosed and crowded environments [6]. There is evidence to suggest that activities that produce more aerosols (e.g. singing, aerobic activity) are also risk factors for these events. Some large outbreaks are shown to be the result of one index case, however in others genomic analysis has revealed several independent introductions, indicating situations of high risk when multiple infected persons are introduced to an environment [7]. For instance, in nursing home outbreak investigations from the Netherlands, Boston, and London, multiple viral genomes were identified, suggesting multiple introductions to the facility leading to infections among residents [8-10]. The case in the Netherlands care home initially appeared to be associated with a church service, but genomic data showed transmission was more likely to have taken place within the care home environment.

Public health strategies are needed to mitigate transmission, particularly for those environments and activities that are most likely to lead to large clusters and superspreading events. Backwards contact tracing is an outbreak investigation approach that aims to trace new cases and their contacts back to the event or place where they originally got infected. It is an essential tool for identifying the setting of the transmission and the index case (s) of a cluster that could be linked to other cases. [11]. Routinely combining forward and backward tracing to identify both potential contacts and the likely setting of the transmission will significantly enhance efforts to reduce the spread of infection.

2.2 Settings and activities

Households and extended family

Living with the case, especially sleeping in the same room, attending family/friend gatherings, and dining were found to have a higher risk for transmission than brief (<10 min) community encounters [12-14]. In household studies secondary attack rates range from 4% to 35%. Having a daily close contact, sleeping in the same room, or dining in close proximity, all increase the risk of infection [2, 12, 15-18] In the same household, frequent daily contact with the index case, and dining in close proximity has been associated with increased attack rates [18-20]. The risk of passing on infection to one's spouse (43,4%) is significantly higher than to other relationships (18,3%) [18]. Similar results were observed in the USS Theodora Roosevelt navy ship outbreak in which those sharing the same sleeping space had higher risk of being infected [21]. Isolation of the infected person away from the family is related to reduced risk of infection [19, 20]. These findings suggest that sleeping in the same room or sharing the same sleeping space and high contact frequency confers an increased risk of transmission.

Hospitality and exposure to public spaces

Poor ventilation and crowding have been suggested to be factors in numerous transmission clusters, including those in bars, churches, and night clubs, karaoke bars [22, 23]. By contrast, such events have rarely occurred outside, and then only in the context of high levels of crowding. Japan, China, South Korea, and Indonesia noted that their largest superspreading events originated from pubs, clubs, restaurants, gyms and wedding venues. An analysis of 3,184 cases in Japan identified 61 case-clusters that were observed in healthcare and other care facilities, restaurants and bars, workplaces, and music events [24]. The largest clusters in Hong Kong were associated with transmission in bars and at a wedding dinner, both locations in which face masks were not worn [23]. At least 246 cases of coronavirus disease (COVID-19) have been linked to nightclubs in Seoul [25]. Close-interaction activities such as traditional markets, religious gathering, and wedding parties contributed most to the spread in Indonesia [26]. A super-spreading event in Vietnam, including analysis using genomics, indicated 12 cases linked to transmission in a poorly ventilated bar, only four of whom had close contact with the index case [27].

There are several studies indicating that many infected individuals have a common setting of exposure such as indoor dining. An outbreak in an air-conditioned restaurant in Guangzhou, China, involved 3 family clusters [28]. In a report from the US found that those infected with SARS-CoV-2 without known close contact with a person with confirmed COVID-19, case-patients were more likely to report dining at a restaurant (aOR = 2.8, 95% CI = 1.9–4.3) or going to a bar/coffee shop (aOR = 3.9, 95% CI = 1.5–10.1) than were control participants [29]. In a study from China where 391 cases and 1,286 of their close contacts were followed up, the secondary attack rate was twofold higher if dining was involved [2]. According to a systematic review including papers published up to 3rd of July, the majority of pre-symptomatic transmission events involved dining in close proximity [30].

There is evidence that increased frequency of exposure to public spaces including shops, cinemas, places of worship and public transport is associated with increased risk of acquiring acute respiratory infections, suggesting a possible important role of casual contact in these settings. [31]. A detailed contact tracing study of train passengers that included 2,334 index cases and 72,093 close contacts found that risks were generally very low, and the secondary attack rate was higher for those in close proximity and with longer duration of shared travel [32]. In Japan, all clusters identified in a study were associated with close contact in indoor environments, including fitness gyms, a restaurant boat on a river, hospitals, and a snow festival where there were eating spaces in tents with minimal ventilation [33]. Sporting events including ice hockey and fitness classes have been cited in several other studies, with the higher aerosol generation due to aerobic activity highlighted as a potential risk [34, 35]. An outbreak investigation in South Korea showed transmission in high intensity dance classes at 12 locations, but not in lower intensity yoga classes or classes with a very low occupant density [35]. The role of ventilation has also been indicated in several epidemiological studies. In a study of household transmission in China, opening windows to allow better air movement led to lower secondary household transmission [19].

Residential and workplace settings

The largest outbreaks from across the world have been reported in long term care facilities such as nursing homes, homeless shelters, prisons, and workplaces including meat-packing plants and factories [22, 36]. In six London care homes experiencing SARS Cov-2 outbreaks a high proportion of residents (39.8%) and staff (20.9%) tested positive for SARS-CoV-2 [9]. Among 408 individuals residing at a large homeless shelter in Boston, 36% of those tested were found to be positive [37]. A key feature of many homeless shelter outbreaks is shared airspace through dormitory style accommodation and communal areas. The EveryOne in campaign in England which closed these facilities and moved people into own room, own bathroom self-contained accommodation is thought to have prevented similar large scale outbreaks in England in the first wave of the pandemic [38]. Although it is much harder to obtain data from incarcerated populations, the largest clusters of cases observed in the USA have all been associated with prisons or jails, suggesting a high infection rate in these institutional settings [39]. While environmental conditions in food processing facilities are also thought to be a risk factor, with the chilled environment likely to increase virus survival, in a study of an outbreak in the largest meat processing plant in Germany, while the universal point of potential contact among all cases was workplace, there were also statistically significant indications of transmission between employees in related locations such as a single shared apartment, shared bedroom and associated carpool [36].

2.3 Contact pattern

There is evidence to suggest contact patterns, including the duration of contact, contact frequency, proximity to the index case and types of activities influence transmission risk, highlighting the need for tailored prevention strategies for different settings. This information was discussed in the EMG Mitigation paper dated 03 June 2020 [1].

Large, long-term care facilities such as nursing homes and homeless shelters have seen increased rates of infection, in part because of patterns of contact among staff and residents. In an investigation of 17 nursing homes that implemented voluntary staff confinement with residents, including 794 staff members and 1250 residents in France, staff confining themselves to a single facility for a weeklong period (stayed in the facility) was associated with decreased outbreaks in these facilities [40].

Other activities identified as high risk include sleeping in the same room and dining in close proximity with the infected person and taking part in indoor group activities [6, 30]. Transmission is significantly reduced when the index case is isolated away from the family, or preventative measures such as social distancing, hand hygiene, disinfection and use of face masks at home are applied [19, 20].

Large outbreaks have been occurred in family, friend, work-related and other gatherings including weddings and birthday parties [22, 41]. Other examples include gatherings in pubs, church services, and business meetings [22, 23, 37, 42]. In non-household contact tracing studies, dining together or engaging in group activities such as board games have been found to be high risk for transmission as well.

2.4 Host factors

Period of infectiousness

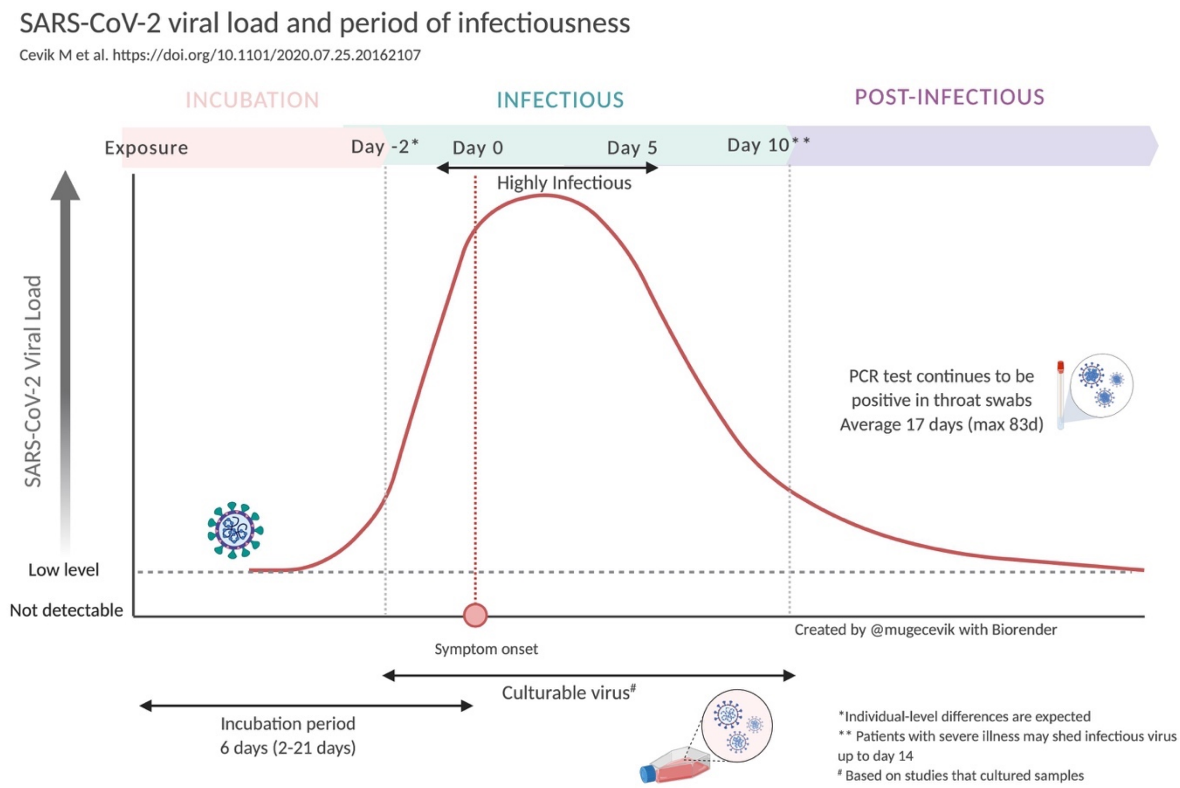
Peak SARS-CoV-2 viral load in the respiratory tract is observed at the time of symptom onset or in the first week of illness with subsequent decline thereafter, which indicates the highest infection potential just before or within the first five days of symptom onset [43] (Figure 3).

This pattern of infectivity indicates that preventing onward transmission requires immediate self-isolation at the onset of symptoms, prompt testing with rapid results and robust forwards and backwards contact tracing. In many countries, people with symptoms access testing late in the disease course, by which time they may have had multiple contacts during their most infectious period. Self-isolation is an extremely important mechanism for interrupting transmission but over 75% of those with symptoms in the UK, and their contacts, report not fully self-isolating [44]. This poses a major barrier to reducing the prevalence of infection and requires the provision of appropriate support for those who need to isolate.

SARS-CoV-2 RNA is detected in the upper respiratory tract for a mean of 17 days (maximum 83 days) after symptom onset [43]. However, detection of viral RNA by qRT-PCR does not necessarily equate to infectiousness, and viral culture from PCR positive upper respiratory tract samples in eight studies have been rarely positive beyond nine days of illness, indicating a likely infectious period of around 9 days from symptom onset for mostly non-severe cases [43]. Severely ill or immune-compromised patients may have relatively prolonged virus shedding, and some patients may exhibit intermittent RNA shedding, although this may not represent ongoing infectivity. However, high cycle thresholds results may be detecting non-infectious viral fragments [43].

While difficulty in culturing live virus from swabs may explain some of the lack of infectiousness in the samples, viral load kinetics corresponds to what is known about transmission based on contact tracing studies, which is that transmission capacity is maximal in the first week of illness. A prospective contact tracing study of 100 confirmed cases of COVID-19 and 2761 close contacts found that secondary infection rates were higher among those contacts whose initial exposure to the index case happened within 5 days of symptom onset with no secondary cases identified 5 days after the symptom onset [15]. Another contact tracing study of 269 lab-confirmed SARS-CoV-2 cases and 161 laboratory-confirmed or probable contacts in the UK found that among 41 who had a point source exposed to the index case a mean of 2.37 days (standard deviation (SD) 3.36) and a median of 1 day (IQR) 0-4) after symptom onset [17].

Figure 3: Period of infectiousness



Asymptomatic and pre-symptomatic transmission

Systematic reviews that only include studies with sufficient time to exclude pre-symptomatic infection have estimated the percentage of SARS-CoV-2 infections that remain completely free of symptoms at 20% (95% confidence interval, CI 17-25%) and 14% (95% CI 5-24%) [45, 46]. While asymptomatic individuals (those with no symptoms throughout the infection) can transmit the infection, their infectiousness seems to be limited compared to symptomatic and pre-symptomatic individuals. In a systematic review (pre-print) that included papers published up to 3 July 2020, secondary attack rates from asymptomatic index cases ranged from 0% to 2.8% (9 studies) compared with secondary attack rates of 0.7% to 16.2% in symptomatic cases in the same studies and pre-symptomatic secondary attack rates ranged from 0.7% to 31.8% (10 studies) [30]. In another review, that included studies published up to 10 June 2020 and identified five studies that directly compared secondary attack rates between asymptomatic and symptomatic index cases, the summary risk ratios for asymptomatic versus symptomatic were (0.35, 95% CI 0.10, 1.27) and for pre-symptomatic versus symptomatic were (0.63, 95% CI 0.18, 2.26) [45].

The contribution of asymptomatic infection to transmission will depend on 1) the relative degree of infectiousness (this is approximately 1/3 as infectious compared to those who have or go onto have symptoms [45]), 2) the proportion of infections that are asymptomatic (recent estimates suggests 20% (95% CI 17%–25%) of individuals remain asymptomatic throughout the infection [45]) 3) the relative number of contacts (asymptomatic cases are unlikely to self-isolate so may have more contacts than symptomatic cases). It is plausible therefore that both asymptomatic and presymptomatic cases make a significant contribution to transmission. People with mild symptoms (paucisymptomatic), who feel otherwise well, still carry large amounts of virus in the upper respiratory tract, which might particularly contribute to transmission of SARS-CoV-2 [43].

2.5 Socio-economic factors

There is a strong association between socioeconomic deprivation, ethnicity and a higher risk of infection [47, 48]. People facing the greatest socioeconomic deprivation experience elevated risk of household and occupational exposure to SARS-CoV-2 [49]. People with lower-paid and public-facing occupations are often classified as essential workers who must work outside the home and may travel to work on public transport. Higher cumulative infection rates were observed in those areas that continued to engage in mobility behaviours consistent with commuting for work [50]. There are low levels of car ownership among the low paid, who are thus more likely to need to travel on public transport [51]. These low-paid occupations often involve greater social mixing and greater exposure risk due to factors such as prolonged working hours and reduced opportunities to practice physical distancing [52].

In addition, housing in socioeconomically deprived areas is more likely to be overcrowded, increasing the risk of transmission within the household [53]. The EpiCov survey in France, people living in cramped or 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. People from black and minority ethnic backgrounds, people with disabilities, migrants, and other marginalised groups have also been shown to be at greater risk of infection, severe disease, and death from COVID-19 [48, 54-57]. These increased risks are also likely due to socioeconomic conditions that increase risk of transmission, inequalities in access to health services, and higher rates of comorbidities due to adverse living and working conditions. These inequalities also shape the strong geographic variations observed in the burden of cases and deaths, both in the USA and the UK [48, 58].

These findings support the hypothesis that the COVID19 pandemic is strongly shaped by structural inequalities that drive household and occupational risks, emphasising the need to tailor effective control and recovery measures for these disadvantaged communities proportionate to their greater needs and vulnerabilities. Analyses of ONS occupational mortality data show increased COVID mortality rates amongst those in occupations which involve high proximity to others, those with increased contact with disease and low paid occupations. Specific occupations at high risk of mortality include social care workers, bus, coach and taxi drivers, and security guards [48]. (20.06.06 SAGE Report - Reducing transmission in high connectivity occupations)

Physical distancing during the 2009 H1N1 swine flu pandemic was effective in reducing infections, this effect was most pronounced in households with greater socioeconomic advantage [59]. Similar findings are emerging for COVID-19, with the ability to practice social distancing strongly differentiated by county and household income [52]. Tackling these inequalities requires structural and economic measures to create supportive physical and social environments, such as social and income protection; support to ensure low paid, non-salaried and zero-hours contract workers can afford to follow isolation and quarantine recommendations; employment protection for people in precarious employment who are required to isolate; provision of protective equipment for workplaces and community settings; appropriate return-to-work guidelines; opportunities for isolation outside of the home to protect other household members, and easy access to testing for them.

Part 3. Evidence update on routes of SARS-CoV-2 transmission

This section covers new evidence updated based on evidence published up to October 2020. Earlier EMG Mitigation paper dated 03 June 2020.

Respiratory transmission

Respiratory particles (small, medium or large) cause infection when they are inhaled or deposited on these mucous membranes [60].Target host receptors are found mainly in the human respiratory tract epithelium, including the oropharynx and upper airway [61]. The conjunctiva and gastrointestinal tracts are also susceptible to infection and may also serve as portals of entry [60, 62].

Although many cases show evidence for respiratory transmission at close-range, there is evidence that under certain circumstances the virus may be transmitted at a distance more than 2 m through aerosols [63]. These include prolonged stay in crowded, poorly ventilated indoor settings. Findings from contact tracing studies in

Japan suggest an 18.7-fold higher risk of transmission indoors compared with outdoor environments [33]. For example, an outbreak investigation from China identified that 24 out of 67 passengers were infected during a 50-minute return bus journey (some were sitting beyond 2 metres from the index case), which was linked to an index case who was symptomatic the day before the trip [64]. In Washington state, a mildly symptomatic index case attended a 2.5 hr choir practice and out of 61 persons present, 32 confirmed and 20 probable secondary COVID-19 cases occurred with an attack rate of 53.3% to 86.7%) [65]. However, these transmission events may have also occurred via close contact, fomite transmission or a combination of different routes.

Direct contact and fomite transmission
Both SARS-CoV-2 and SARS-CoV-1 remain viable for many days on smooth surfaces (stainless steel, plastic, glass) and for longer periods at lower temperature and humidity (eg, air conditioned environments) [61, 66, 67]. Viable SARS-CoV-2 has been isolated for up to 3 hours from aerosols and up to 72 hours from surfaces; the longest reported viability was on plastics and stainless steel, with half-lives around 6 hours [68]. Thus, transferring infection from contaminated surfaces to the mucosa of eyes, nose, and mouth via unwashed hands is a possible route of transmission.

Most reports suggesting fomite transmission are anecdotal and there are relatively few reported in the published literature. In a cluster of infections associated with a mall in China, several affected persons reported no direct contact with cases. The investigators noted that these individuals used shared common facilities (such as elevators and restrooms) and proposed fomite or respiratory transmission in those settings. A case in China associated with indirect transmission via an elevator suggests poor hygiene behaviours resulted in “snot-oral” transmission via surfaces, although it is also possible that aerosols in the elevator could explain the transmission [69]. Given SARS-CoV-2 is readily inactivated by commonly used disinfectants, there is potential value of surface cleaning and handwashing [67]. Unpublished data has found high levels of SARS-CoV-2 RNA on the hands of individuals who are infected, and there is evidence that regular handwashing markedly decreases the risk of respiratory infections, including seasonal coronaviruses. (Hand hygiene to limit SARS-CoV-2 transmission SAGE 30/06/2020). Since the mechanism of action of handwashing is primarily by reducing direct contact and fomite transmission this is strong evidence of the importance of this form of transmission. This route of transmission may contribute, especially in facilities with communal areas such as in nursing homes, with increased likelihood of environmental contamination [66].

The evidence for transmission via surfaces and fomites suggests risks are greatest when the infectious person is present in the environment or for a short period of time afterwards. A number of anecdotal reports that indicate the presence of viral RNA but no live virus on frozen food suggesting surface transmission risks may be more important at low temperatures.

Faecal-oral transmission

The roles of faecal and urinary shedding in SARS-CoV-2 transmission remain to be fully understood. SARS-CoV-2 RNA has been found in stool samples and RNA shedding often persists for longer than in respiratory samples; however, isolation of live virus has rarely been successful from stool or urine [43]. While the gastrointestinal tract probably is also susceptible to infection and may serve as a transmission portal given the high concentration of ACE2 receptors in the small bowel, no published reports have described faecal-oral transmission. In SARS, faecal-oral transmission was not considered to occur in most circumstances; but, one explosive outbreak was attributed to aerosolisation and spread of the virus across an apartment block via a faulty sewage system [70]. Indirect evidence of similar transmission has been reported for SARS-CoV-2 in China, although no direct evidence has been presented, except for the positive RNA samples in the bathrooms [71]. However, overall it appears to be a rare occurrence so far with SARS-CoV-2.

Animal studies of transmission

An increasing body of animal studies (ferrets and hamsters) support the airborne and contact route of transmission. A recent study moving sentinel hamsters into cages vacated by infected animals showed no transmission in these circumstances [72]. Animal studies also suggest respiratory transmission, with a recent pre-print (not yet peer reviewed) suggesting transmission over more than 1m distance [73]. Animals studies also begin to reveal the infectious dose required for SARS CoV2 to establish infection. A recent report estimated this at 5 infectious units [74].

SARS-CoV-2 mutations and transmissibility

As SARS-CoV-2 has spread globally, like other viruses, it has accumulated some mutations in the viral genome which contains geographic signatures that help researchers with virus characterisation and understanding of epidemiology and transmission patterns. In general, these mutations have not been attributed to phenotypic changes impacting viral transmissibility or pathogenicity. G614 variant in the S protein has been postulated to increase infectivity and transmissibility of the virus [75]. Higher viral loads were reported in clinical samples with virus containing G614 than previously circulating variant D614, although there was no association with severity of illness measured by hospitalisation outcomes [75]. However, these findings have yet to be confirmed in regard to natural infection. Nevertheless, the predominance of this mutation across the world illustrates how transmissibility will be a prominent driver of virus evolution at least while population immunity remains low.

Conclusion:

- The evidence base around transmission for this new virus is challenging to establish and will continue to emerge for a considerable time. New studies to increase our understanding of transmission are essential, and analysis from genomics is important to more confidently understand patterns of transmission.

- The evidence base around transmission for this new virus is still emerging but we are not able to wait for definitive answers before deciding on actions. This document is based upon an assessment of the balance of best available evidence at the time. Embedding routine collection of high-quality data into our responses, within a strategic approach to research and knowledge generation, will accelerate the production of new evidence that is required to support the most effective combinations of responses.

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