Transmission of SARS-CoV-2 and Mitigating Measures

EMG-SAGE 4th June 2020

Executive summary

- Transmission of SARS-CoV-2 is most strongly associated with close and prolonged contact in indoor environments. The highest risks of transmission are in crowded spaces over extended periods (*high confidence*).
- Physical distancing is an important mitigation measure (*high confidence*). Where a situation means that 2m face-to-face distancing cannot be achieved it is strongly recommended that additional mitigation measures including (but not limited to) face coverings and minimising duration of exposure are adopted (*medium confidence*).
- Selection of prevention and mitigation measures should consider all the potential transmission routes and need to be bespoke to a setting and the activities carried out (*high confidence*).

Key conclusions

1. We consider the following:
    - Evidence relating to transmission of COVID-19 as at 3rd June 2020;
    - The potential effectiveness of a range of different prevention and mitigation measures, and the factors that will determine this;
    - Selecting measures to effectively control all the transmission mechanisms for the disease;
    - How measures in the UK compare to other countries;

2. Understanding transmission:
    - Transmission of SARS-CoV-2 is most strongly associated with close and prolonged contact, suggesting that close-range direct person-to-person transmission (droplets) and indirect contact transmission (via surfaces and objects) are the most important routes of transmission.

    - There is weak evidence that aerosol transmission may play a role under some conditions such as in poorly ventilated crowded environments. This evidence is predominately from one outbreak investigation. Laboratory bio-aerosol experiments show that SARS-CoV-2 can survive in the aerosol state for over 1 hour.

    - There is evidence for asymptomatic transmission and weak but evolving evidence for super-spreading events where a small number of people infect large numbers of others. Given that these people may be asymptomatic (and thus not coughing or sneezing) it is possible that they are able to disperse large amounts of virus through normal respiratory activities.

3. The role of physical distancing:
    - There is a non-linear relation between the risk of transmission and distance of separation for face-to-face contact. Duration of this contact is also important with risk proportional to time. Given the uncertainties about transmission and dose-response it is not possible to say with

certainty what a safe distance of separation is, but best current evidence suggests that 1m carries between 2 and 10 times the risk of 2m of separation.

- Where it is necessary for people to be closer than 2m face-to-face for a prolonged period or where someone has multiple frequent interactions with others at shorter distance, additional measures will be required to disrupt close-range transmission. In most cases this is likely to be based on limiting duration of contact, using face coverings and orientation of people.

- Countries that specify a separation distance below 2m generally mandate other mitigation measures, usually face masks or face coverings as a minimum. The exception is Australia which recommends 1.5m and does not mandate face coverings but, this is in the context of very low disease prevalence.

- Outdoor transmission remains low risk through aerosol and indirect contact routes, but face-to-face exposure (e.g. ≤2m for a prolonged period) should still be considered a potential risk for transmission via respiratory droplets.

4. Prevention and mitigation measures:
   - Selecting prevention and mitigation measures should use a "hierarchy of control" approach as described in the EMG paper [C]. It is important to ensure that measures are in place to cover all the transmission routes, and groups of measures are likely to be needed to ensure this is achieved. Graphical methods may be beneficial to help organisations visualise the impacts and interactions of different measures.

   - Evidence relating to hand-hygiene and face coverings includes a number of randomised trials and meta-analyses. A recent meta-analysis study has also considered the role of distance in transmission and is consistent with our analysis around this measure.

   - Given the very recent origin of this novel virus, very few engineering or environmental mitigation measures have strong evidence to support their effectiveness. A number have data from idealised studies to show theoretical efficacy, but there are very few real-world studies. Decisions on selection of engineering controls will inevitably need to be based on incomplete evidence as "do nothing" is not an option. Appropriate controls should be identified through collaborative risk assessments carried out between employers and employees.

Overview of modes of transmission

5. Transmission is still thought to occur through three main mechanisms as illustrated in Figure 1:
   - **Close-range direct person-to-person transmission** happens when someone is directly exposed to the respiratory droplets emitted by another person. These virus carrying droplets and aerosols can lead to virus entering the body through eyes, nasal membranes, oral mucosa, or the respiratory system. Close range transmission can also be through direct physical contact with the infectious person.

- **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.
- **Aerosol transmission** occurs when small virus containing respiratory droplets evaporate to less than 5 micron diameter particles (droplet nuclei) and are carried by the air, where they are subsequently inhaled. This may be released from respiratory actions (breathing, talking, coughing etc) as well as through aerosol generating procedures in a hospital or dental environment. These particles principally transit infection over short distances but potentially could transmit over longer distances (<2m) too.

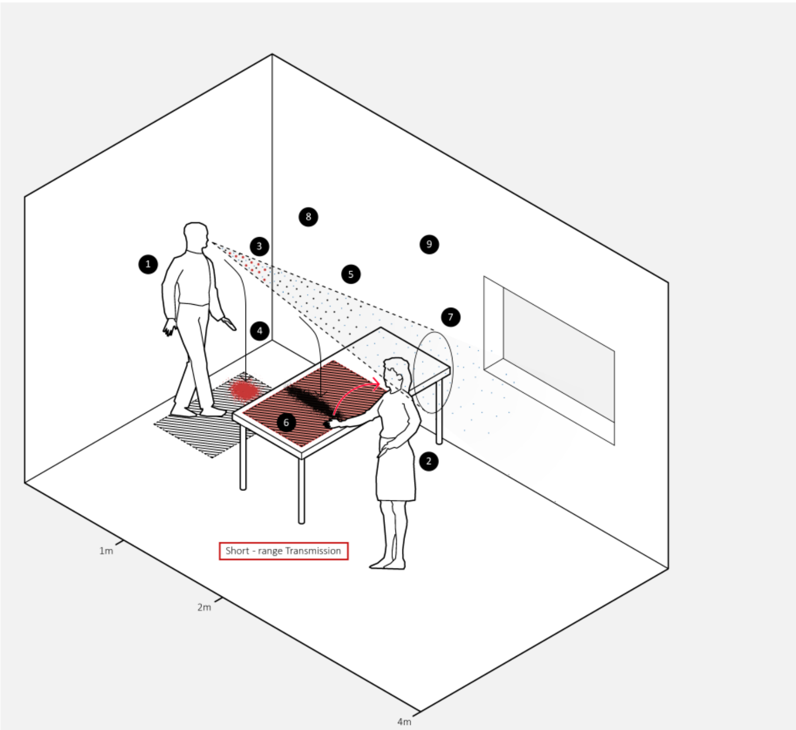

Figure 1: Illustration of the transmission routes for COVID-19 (image adapted from [1] and [2]

6. Infection requires inoculation by sufficient number of viral particles to cause infection – the number of particles required to cause infection is not yet known. However, the infectious dose received depends on the **quantity of infectious virus x the duration of exposure**, and hence **both** must be considered when evaluating risk.

7. Risk of transmission depends on a number of factors. These have been set out in previous EMG papers [A,B,C], but the key factors are reiterated here for clarity:
   - The highest risk for *close-range transmission* is when someone is face-to-face with an infectious person at a distance of 2m or less for a prolonged period. The risk increases with the amount of time spent in close proximity to the infectious person and with the reduction of distance. A calculation based on [3] suggests risk at 2m face-to-face is around 10 times lower than the risk at 1m. A new meta-analysis paper of reported transmission suggests that the risk of transmission at 2m separation is approximately half that at 1m, although this does

not consider the orientation or the mode of transmission [4]. When people are side-to-side or behind one another risk is via aerosols and so is determined by the influence of ventilation; at 1m the exposure risks would be similar to 2m when face-to-face in an indoor environment

- Risk of *contact transmission* increases with the proximity to the infectious person (surfaces close by are more likely to be contaminated), the number of surfaces touched, virus survival on hands and surfaces, and higher frequency face touching behaviour. Frequent cleaning of hand touch surfaces and good hand hygiene reduce risk. Virus is not likely to survive for long periods of time on outdoor surfaces in sunlight, but may survive for more than 24 hours in indoor environments.
- Risk of *aerosol transmission* is highest when people share poorly ventilated spaces where the viral aerosols can build up rather than being diluted and removed by the ventilation. Risk increases with time spent in the same shared air. Risk is generally higher closer to the infectious person, but beyond this close proximity the concentration of aerosols that a susceptible person will be exposed to depends on the ventilation in the room. Transmission by aerosol can happen at distances beyond 2m in the same enclosed space especially if the ventilation is poor and duration of exposure is sufficient. It is possible but unlikely that aerosol transmission can happen between people in different rooms (via ventilation systems). Aerosol transmission risk is considered to be very low outdoors due to high dilution of virus carrying aerosols and UV inactivation of the virus.
- The amount of virus released by an infected person and its dispersion characteristics facilitates the transmission. Dispersion is governed by complex flow physics as described in previous EMG papers[A,B]. Key factors include the type of respiratory activity (a sneeze generates the most particles, breathing and talking produce less), the velocity of the release (a cough or a sneeze is more violent than breathing or talking and hence the droplets can travel further and with higher momentum). Virus could also be introduced via nasal discharge through contamination on hands. The point at which the exposure occurs in the disease progression of the infected individual may also be important. There is evidence that viral shedding depends on the progression of the disease and may be highest the day prior to symptom onset [5]. No viable virus has been recovered from air samples taken in hospitals from patients who generally are at a more advanced stage of infection. Viral RNA has only been recovered occasionally at low levels, although one study suggests it is higher for patients in the first week of illness [6] . There is limited quantitative data yet to indicate how this varies between people.
- Transmission may also be influenced by environmental conditions. As detailed in previous EMG papers[A,B,D], the virus is stable on surfaces and in air under laboratory conditions that simulate indoor environments. The virus survives better under colder, drier conditions with survival times of hours to days. Experiments under simulated sunlight suggests that high exposure to UV in outdoor environments will reduce the survival time to the order of minutes, however this will depend on the time of year and the cloud cover.

8. All of the issues identified above are important to consider when developing a risk assessment. Given each job comprises a mix of individual work activities, it will be important to identify the factors that influence risk and the appropriate mix of prevention and mitigation at the level of the work activity to reduce these risks to levels which are as low as reasonably practicable. This

underlines the need for front line employees as well as managers to be involved in risk assessment preparation.

Latest evidence for importance of different modes of transmission and key factors

9. Evidence that transmission is predominantly occurring in indoor spaces where people are in close proximity continues to grow [7]. Care homes and hospitals have been recognised as high risk environments. Household transmission also remains one of the most significant environments (considered in SPI-M and SPI-B papers) and hence continuing to provide guidance to households and public health messaging on mitigating transmission is important[8]. An increase in work place contacts will increase risk of infection, and is thus likely lead to further household transmission.

10. Recent animal studies [9], [10], [11] have shown that transmission can occur without direct contact between animals housed in separate but closely located cages, confirming that close range droplet and/or aerosol routes are important (it is not possible to determine from these experiments whether transmission was through droplets, aerosols or both). CDC in the USA have recently clarified their information on transmission to indicate that direct person-to-person exposure is likely to be the predominant form of transmission.

11. There are growing numbers of anecdotal reports of outbreak clusters, where one person is responsible for localised clusters (super-spreading events involving multiple highly over-dispersed numbers of secondary cases), sometimes over a relatively short time period (typically hours). Very few of these outbreaks have been formally reported in the academic literature yet, and those which have contain very limited information on the environment and routes of transmission. However the types of environments and circumstances of transmission are concerning as the involve commonly practised communal activities. At least two outbreaks with a high attack rate have been associated with choir rehearsals and several clusters are associated with religious settings, parties, bars, restaurants, and nightclubs. The Skagit Chorale outbreak [12] resulted in 33 confirmed and 20 probable cases among 61 people from one infector in a 2.5 hour period. Transmission could include contact and close-range as well as possible aerosol transmission which may be exacerbated through singing.

12. There is good evidence that presymptomatic and asymptomatic transmission occurs, and may underpin some of these clusters. These people are not necessarily coughing and sneezing, but they are shedding sufficient virus to cause multiple secondary cases through normal respiratory activities and/or through contamination of surfaces. A case in a church in Singapore [13] identified transmission to one person who sat in the same seat as an infector at a subsequent event suggesting transmission through contaminated surfaces. A cluster in a shopping mall in China indicated some close contact, but several cases occurred with no direct contact and hence transmission through “virus contamination of common objects, virus aerosolization in a confined space, or spread from asymptomatic infected person” was implicated. The areas proposed for this transmission were restrooms or elevators [14]

13. A new meta-analysis study [4] considered influence of distance and the application of face masks and eye protection (face shields) on the transmission of SARS, MERS and SARS-CoV-2. This does not provide detail on the mechanisms for transmission, but shows how these factors influence the risk of exposure. The paper reports that a physical distance of more than 1 m probably results in a large reduction in virus infection (adjusted relative risk 0.20 (95% CI 0.10-0.41)); for every 1 m further away in distancing, the relative effect might increase 2·02 times (95% CI 1.08-3.76; p=0.041). The paper considers masks and eye protection as exposure controls only and shows both reduce risk but with low certainty in the evidence. It should be noted that many of the papers within this meta-analysis are from healthcare settings and all are based on indoor environments.

14. In a recent single study infectious virus has been isolated (but not enumerated) from faeces [15].While there is not yet any evidence of transmission, this may raise the possibility of transmission through contact with faecal matter and potentially during toilet flushing or faulty building drainage systems. Transmission through direct exposure to droplets, inhalation of aerosol in bathroom environments or contamination of surfaces including hand washing facilities in bathroom environments could be possible, although there is no evidence currently to suggest that it is a significant route.

15. Two recent computational studies [16], [17] have modelled dispersion of respiratory droplets in outdoor conditions and shown that the wind can carry droplets further than 2m. Neither of these studies have been validated in a real-world context and neither take account of the infectious dose needed to initiate infection, but one showed that the fraction of respiratory droplets that deposited on a person at a distance of a 1.83m (6ft) doubled at a wind speed of 4 m/s compared to 0 m/s. There is no further evidence for transmission outdoors, and EMG believe that the risk outdoors remains very low. However we remain of the view that face-to-face transmission could be possible and the ability for wind to keep droplets airborne means that we recommend that people continue to observe a distance of 2m when face to face and avoid prolonged exposure to other people.

16. Many gaps in knowledge remain about the importance of different transmission modes and factors that influence them. We recommend that the investigation of outbreaks to a standardised protocol that includes environmental factors should be a priority in order to understand how transmission is happening across different settings.

Choosing prevention and mitigation measures

17. Creating an environment that minimises the possibility of covid transmission requires appropriate actions to prevent and mitigate risk. As detailed in EMG paper [C] this should consider **all of the known transmission routes** together with the **time that someone is exposed**. It should also consider the chance of coming into contact with an infected person, which will depend on the nature of the job, the prevalence of the virus in the population and the level of vulnerability of susceptible people. A greater level of mitigation will be needed where:
    - The environment includes people who are particularly vulnerable to COVID;
    - People are at high risk of exposure to someone with COVID;

- People are exposed to individuals where there is little record of who they came into contact with, thus reducing the opportunities for contact tracing (e.g. public transport and other public spaces);
- The nature of a job means it is likely that people will be in close proximity other people;
- The nature of a job means it is likely that people will be highly networked and therefore may act as transmission amplifiers (see SPI-B paper on social networks 04/06/2020).

18. The efficacy, effectiveness and confidence in the evidence for 39 identified prevention and mitigation approaches is set out in **Table 2**. This considers the hierarchy of risk and the route(s) that the measure can prevent or mitigate. The efficacy is considered to be the theoretical performance under ideal conditions, while the effectiveness considers the real-world performance which takes into account likely impacts of technical limitations and behavioural aspects. Scores for efficacy, effectiveness and confidence are based on expert views from 14 people within EMG, who scored independently using a 5-point Likert scale. This was carried out rapidly to provide an initial assessment. Factors such as practicality and cost are not considered in this assessment, but are discussed in **Table 3** which summarises the rationale for each option.

19. This is a novel disease with a small but rapidly developing evidence base. There are very few randomised controlled studies, and very few systematic reviews or meta-analyses. In assessing our confidence in the evidence we have taken account of this limited nature and volume of evidence, the quality of the studies, and the risks of different forms of bias, including publication bias. It should also be noted that this has been carried out rapidly and hence there are unavoidable limitations to the analysis.

20. In selecting appropriate measures it is important to identify combinations of approaches that address all the potential routes of infection (direct person-person, indirect surface contact, aerosol) and that are bespoke to the environment and the activities that are carried out.
    - Some measures act as preventative barriers that limit exposure to a source of infection, while others act as mitigation barriers that limit the consequences when exposure does happen. Several measures act as both prevention and mitigation.
    - Some measures act against only one transmission route, while others are able to prevent or mitigate more than one route. In some cases it is possible that the introduction of a measure could raise the risk of transmission through another route, or have other negative consequences. Care should be taken to consider bot the intended and unintended consequences any particular approach.
    - The potential for interactions between different measures is not yet well understood. While some measures may be predicted to only have a small effect if applied in isolation, applying multiple measures in combination will lead to much greater, and in some cases synergistic, effects.

21. All measures should be considered in the context of the disease prevalence in the environment and the risk of exposure to an infectious person. When there is a high prevalence of disease stringent measures and good adherence are important for both personal protection and to stem the transmission of the disease in the community. When prevalence drops to a sufficiently low level it is likely that measures can be relaxed considerably in most environments. Taking these

decisions will need to weigh up the likelihood of exposure, the vulnerability of the people concerned and the wider consequences to society. It is important to have good confidence in the prevalence of the disease in order to make these judgements effectively. It may be appropriate to link measures to Joint Biosecurity Centre alert levels provided these are robust.

22. There is currently insufficient evidence on transmission to be able to confidently quantify absolute risk of infection and the impact of mitigation measures. For some modes of transmission it may be possible to use surrogate approaches, computational models or data from other diseases to estimate the relative effects of prevention and mitigation measures. However as many of these are environment specific it can be difficult to quantify with a high degree of confidence. There is a well-established concept of “tolerable risk” which is defined by HSE as “…’tolerable’ does not mean ‘acceptable’. It refers instead to a willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking and that it is being properly controlled” .

23. Visual approaches can be a useful tool to consider the application of different control measures. A Bowtie diagram (Figure 2) can be used to show how different preventative and mitigation barriers can be applied to consider their impact on interaction points and different transmission routes. A coloured block can be used to show where a particular prevention approach applies to a particular interaction or how a mitigation measure impacts on a transmission route. It is important to have at least one coloured block on each strand. A higher number of coloured blocks would provide greater confidence of more effective reduction in transmission. It can also enable easy identification of those measures that are both preventative and mitigating, or those that only act in one way.

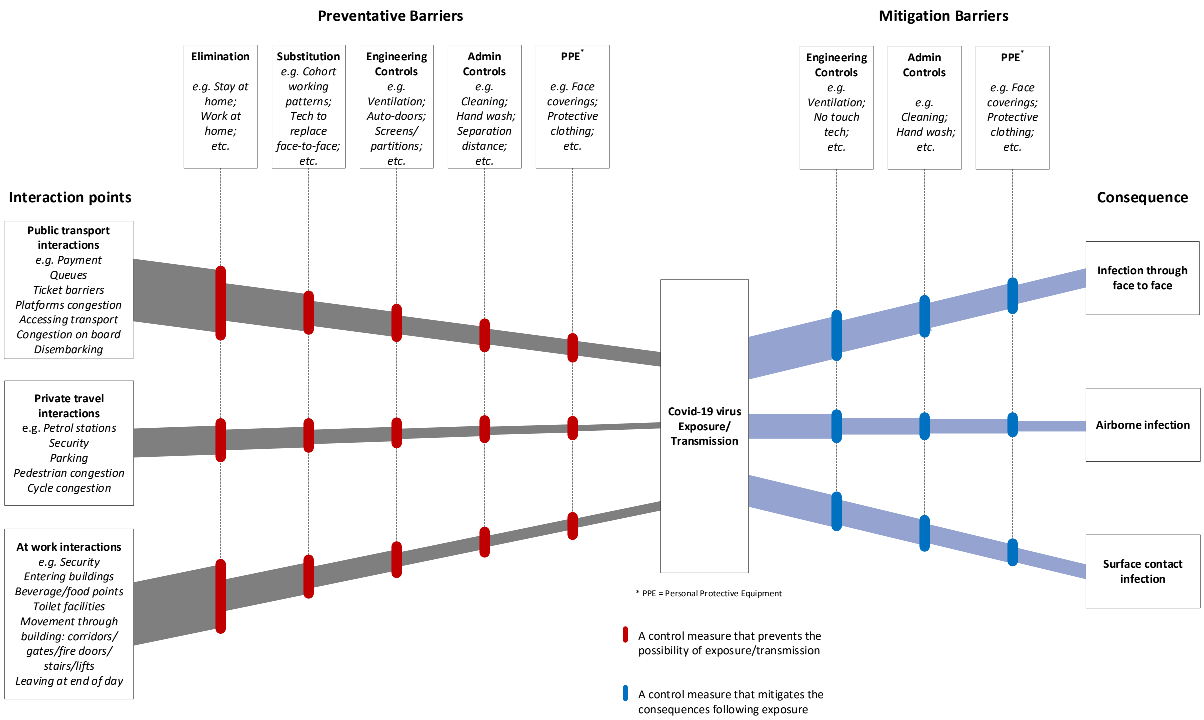

Figure 2: Bowtie diagram that can be used to graphically determine appropriate prevention and mitigation measures

International Comparisons

24. Table 1 provides a summary of current environmental and personal mitigation measures required in a number of other countries to enable working and public interactions. All countries recommend good hygiene practices including cleaning, handwashing and using tissues to catch coughs and sneezes, and we have therefore not highlighted those. The UK is most similar to the USA and Canada, both in having a current high number of cases, approximately 2m distancing and few mandated additional measures. Where physical distancing is less than 2m the majority of countries mandate additional specific prevention and mitigations measures (in most cases face masks/coverings). The exception is Australia which specifies 1.5m but has a very low number of cases.

Table 1: Environmental and personal mitigation measures in a number of countries.

High case countries (4,000+ cases over past 5 days)	
USA	At least 6ft, face coverings recommended in public, CDC guidance updated to recognise that most transmission seems to be direct person-to-person in close contact. Workplace guidance recommends face coverings and improving ventilation, worker health checks (eg symptom/temperature), risk assessment to determine measures
UK	2m, face coverings recommended in enclosed spaces where physical distancing is impractical, but not mandatory (except for infection prevention and control in healthcare), risk assessment for workplaces, ventilation recommended as a workplace mitigation
France	At least 1m, masks are mandatory on public transport and taxis if there is no separation from the driver, masks are not mandatory in shops but can be required by the shopkeeper.
Canada	At least 2m, face coverings recommended where 2m is hard to maintain including public transport and shopping. Workplaces should implement measures to ensure distancing or use physical barriers and consider face coverings where distancing is difficult.
Medium case countries(150-4000 cases over the past 5 days)	
Singapore	At least 1m for events, public venues, workplaces. Wear a mask to leave your house (2 year old and above), avoid social interactions in work places, logging of workers and visitors.
Germany	1.5m, transparent screens must be installed in public spaces, masks mandatory on public transport and public places. Employers must provide masks.
Spain	Recommend masks on public transport, 2m in workplaces
Italy	1m for public spaces including cafes and shops as well as workplaces, temperature measurement in workplaces, travel restrictions between regions. Masks (age 6+) mandatory in closed spaces including transport and where it is not possible to guarantee the safety distance.
Low case countries (less than 150 cases over past five days)	
New Zealand	2m recommended in uncontrolled environments (supermarkets, shopping, parks) where you don't know people and they can't be contact traced. 1m in controlled environments (work, church, clubs etc) where there is a contact tracing register. Guidance linked to the alert system
Australia	1.5m as far as possible in public, improve ventilation in workplaces, avoid social spaces and meetings in workplaces, need a C-19 plan

Hong Kong	Wear a mask with symptoms, wear a mask in public transport or crowded places (surgical – fluid repellent), ventilation, cleaning, maintenance of drainage pipes, temperature checks, no distance seems to be specified

Table 2: Impact of mitigation measures on three transmission routesranked in terms of Efficacy (theoretical performance), Effectiveness (real-world performance) and the Confidence in the quantity and quality of evidence.

Very low | Low | Medium | High | Very high | No response

Hierarchy	Mitigation	Short range	Air	Contact	Efficacy	Effectiveness	Confidence
Elimination	Prevent the presence of an infector in the environment*	***	***	***			
	Remove the use of a particular environment	***	***	***			
Substitution	Reduction of time spent in an environment*	***	***	***			
	Change work patterns to work in a cohort*	***	***	***			
	Move to outdoor working	**	***	**			
	Changes to restrict “loud” activities (e.g. reduce talking time, no singing)	***	***	*			
	Technology to replace face-to-face interactions	***		***			
Engineering	Anti-microbial surfaces			***			
	No-touch technologies			***			
	Provision of new hand wash stations			***			
	Screens/partitions	***	*	**			
	Increased fresh air ventilation rate	*	***	**			
	Change to room air distribution patterns	**	***	*			
	Application of room scale air cleaning/UV devices	*	***	*			
	Installation of local exhaust systems or local air cleaning devices	***	***	*			
	Propping open internal doors to enhance airflow		***				
	Personalised ventilation systems	**	***				
	Use of UV/HPV decontamination		***	***			
	Good maintenance of sanitation/drainage systems		**	***			
	Enhanced daylighting in buildings		*	**			
Administration	Frequency of high touch surface cleaning			***			
	Frequency of general room surface cleaning			***			
	Training on quality and effectiveness of cleaning			***			
	Provision of hand sanitiser			***			
	Replacement of jet dryers with paper towels		**	***			
	Avoid sharing equipment (e.g. IT, hotdesking)			***			
	Management of waste			***			
	Hygiene behaviours in bathrooms (e.g put the toilet seat down)		***	***			
	Changes to touch behaviours (e.g. education programmes)			***			
	Lower density of occupants	***	***	***			
	Maintain 2m distancing	***	*	**			
	One-way systems for moving through spaces	***					
	Orientation of people	***		*			
PPE	Respirator (N95/FFP3) face masks	***	***				
	Surgical face masks	***	**				
	Face coverings	***	*				
	Gloves			***			
	Protective clothing	*		***			
	Face shields/goggles	***	*				

Table 3: Summary of rationale for each measure including the evidence available and practical considerations. Further detail on evidence is available in previous EMG papers [A-F] and the companion paper [G].

Hierarchy	Mitigation	Rationale and considerations
Elimination	Prevent the presence of an infectious person in the environment	Rationale: Removal of infectors eliminates the source of the hazard – in this case the virus - and thus reduces the risk of others becoming exposed and infected. The need for other controls is therefore negated. Evidence: Strong evidence from clinical and societal practice that a disease cannot be passed on if an infectious person is effectively isolated. Practical considerations: This would be through actions such as effective test, trace, isolate approaches at both national level and through effective application within organisations. Environments that can track people on their premises will likely have greater success than those that are public with no records. Feasibility relies on the being able to detect and quickly react. This will be more effective with lower prevalence of virus. Asymptomatic carriers reduce the real-world effectiveness as they are much harder to detect. Social factors (e.g. financial issues if staff don't work, people ignoring rules) reduce the effectiveness.
	Remove the use of a particular environment	Rationale: Closure of some high contact or high risk environments can remove the potential for infection. This could be a whole organisation or just selected environments within an organisation. Evidence: Evidence from modelling and experience in the current pandemic that environments which enable a high degree of social contact (bars, restaurants, religious settings etc) are associated with clusters of cases. Evidence to show that closure of spaces within an organisation (e.g. cafeterias) is effective is weaker. Practical considerations: Closure can be very effective but needs full cooperation of the organisation and may require financial incentives to support the action. Closure of some environments has knock on impacts on other factors (e.g. dentistry/health services, impacts on mental health).
Substitution	Reduction of time spent in an environment	Rationale: Shorter times in roles where face-to-face contact could happen can reduce duration of exposure to infectious people and reduce likelihood of transmission. Evidence: Good evidence from analysis of other respiratory infections and modelling studies that risk is related to duration of exposure. There is insufficient data on the infectious dose of SARS-CoV-2 virus required for infection to be able to specify a safe duration of contact. In addition this is likely to be subject to uncertainties such as

		environmental conditions (light levels, temp, RH), any level of viral shedding by an infected individual and mechanical ventilation influences. Practical considerations: Feasibility will depend on the flexibility of a work environment and ability to manage roles differently.
	Change work patterns to work in a cohort	Rationale: Cohorting workers/groups limits the size of the network where the virus can spread. If there is a case of infection, it is less likely that it will be spread widely within a workforce. Evidence: Modelling papers from SPI-M support this. Practical Considerations: Feasibility will depend on the flexibility of a work environment and ability to manage roles differently. This is detailed in the SPI-B paper on social networks (SAGE 04062020).
	Move to outdoor working	Rationale: Likely to reduce the amount of surface contamination as decay rate on surfaces is likely to be higher outdoors. Aerosol is more effectively dispersed than in an indoor space. Face-to-face exposure is still possible. Evidence: Very few reports of transmission of SARS-CoV-2 in outdoor environments. Some modelling studies suggest the wind can carry particles further, but no consideration of dose. Laboratory evidence to show shorter survival times for virus in bright sunlight. Practical considerations: Weather and role dependent. Enclosing outdoor spaces may increase risks. In many environments it is easier to enable physical distance between people when outside. May be issues with accessibility for some people.
	Changes to restrict "loud" activities (e.g. reduce talking time, no singing)	Rationale: Louder activities produce higher numbers of aerosols and droplets which could lead to higher viral emission rates. Activities increase breathing rate which could increase exposure. Evidence: Small amount of mechanistic evidence from studies measuring droplet production, high rates of transmission reported in several choirs and religious groups. No conclusive evidence of higher viral loads through different respiratory activities or that it is the singing activities that are responsible. *EMG have noted this is a research gap which would be important to address for opening up musical activities, including the importance of wind and brass instruments.* Practical considerations: Impact is likely to be low for most environments; however there is sufficient concern around singing and musical activities that activities have been restricted. There is a significant lack of evidence in this area.

	Technology to replace face-to-face interactions	Rationale: Application of mobile phone based readily-available systems such as remote ordering, "click and collect" in hospitality, retail and food sectors which can substantially reduce face-to-face exposure and in some cases can eliminate this. Evidence: Evidence that lower levels of contact at a greater distance reduce transmission, but weak evidence that technology interventions specifically achieve this. Some technologies can introduce risks as touch screen surfaces have been shown to harbour microorganisms that can be transferred between users. Practical considerations: May require technology investment (although paper based is feasible) so cost/time are factors. Potential social impacts through impact on jobs in some sectors. Digital technologies should be used with care where their introduction results in a new surface that has lots of contacts – need to be careful that these don't become a "hot spot". May add new challenges in cleaning of technology interfaces (touch screens) as harsh cleaning agents can often not be used. Touch screens in high risk settings such as healthcare or pharmacies should be treated with a high degree of caution.
Engineering	Anti-microbial surfaces	Rationale: Use of surfaces with an anti-microbial finish could enhance the decay rate of virus Evidence: Effectiveness is shown for bacteria. Limited evidence yet for viruses in laboratory studies although there are studies emerging to show inactivation of coronaviruses. Limited evidence to show impact on transmission in real-world settings. Practical considerations: It is important to consider the time component of viral decay relative to frequency and duration of contamination. To be effective on high-touch sites it would rely on rapid inactivation of virus on surfaces to prevent onward transmission within a short period of time. Many surfaces are unlikely to have sufficiently rapid action to achieve this. Would need to consider which surfaces are most important.
	No-touch technologies	Rationale: Contactless technology can prevent cross-contamination and improve infection control as it removes the fomite transmission pathway. Alongside digital approaches, there are also a range of low-touch methods such as elbow operated taps, foot operated door openers etc. Evidence: Evidence that contact transmission plays an important role. No specific evidence to support the reduction of infection through contactless technology. Practical considerations: Requires behaviour change and in many cases use of smart phone apps or installation of sensor technology which can be expensive. Some digital and mechanical approaches can have accessibility issues, however other technologies (e.g. remote door opening) can improve accessibility.

	Provision of new hand wash stations	Rationale: Good hand hygiene is critical to limit fomite transmission, frequent hand washing with soap removes viruses to stop them spreading, visible provision of wash hand basins. Evidence: Lack of hand washing facilities are major deterrents for implementation of hand hygiene and the visibility of sinks is thought to have a direct impact on the handwashing frequency and duration Practical considerations: plumbing a water supply, potential crowding around sink facilities, possible transmission from contact with the tap, need to keep the facility clean.
	Screens/partitions	Rationale: Physical partitions are expected to be effective at blocking larger droplets but unless they are designed to be completely enclosed will enable passage of smaller aerosols. Evidence: There is no available evidence yet on the efficacy of physical partitions on SARS-CoV-2 transmission. However, there is some evidence that screens and enclosures can be effective in reducing exposure to airborne material in occupational settings, although the details of the enclosure are important. Evidence on influenza exposure reduction is available for smaller barriers such as face shields. Practical considerations: Effectiveness will depend on design – many screens will require gaps to enable items to be passed between people and this should be considered carefully to minimise gaps at head height that could allow direct passage of the aerosol and droplets. Should also consider whether the screen blocks ventilation and hence raises the aerosol risk.
	Increased fresh air ventilation rate for poorly ventilated spaces	Rationale: Increasing the ventilation rate dilutes the concentration of fine aerosols and removes them from a room. This benefit is for the general population in a room, not just those in close proximity to an infected person. A lower concentration means that someone is less likely to inhale an infectious dose during their time in the room. Evidence: A systematic review suggests that less than 2 air changes per hour increases TB transmission risk. Several outbreak analysis and modelling papers correlate degree of risk with the number of particles inhaled and hence the ventilation. Practical considerations: Focus should be on poorly ventilated environments as this will have the greatest benefit; improving an already well-ventilated space will likely have a limited effect. Feasibility will depend on the design of the ventilation system and could be achieved through utilisation of natural ventilation (such as opening windows and vents) and increasing mechanical flow rates where possible and tolerable. Measurement of air change rates in use can be difficult, but approaches such as using CO_2 sensors could be used to indicate ventilation efficacy. Unintended negative consequences (such as noise, security, thermal comfort) should be considered, particularly in high risk environments such as healthcare. Guidance is given by engineering professional bodies (CIBSE).

	Change to room air distribution patterns	Rationale: Airflow patterns can result in zones of relatively stagnant air in a room where someone may be subject to air with a higher concentration of virus. It is therefore preferable to set the air distribution so that fresh air being provided to the room reaches all areas of the space. Pressure differences between zones can move air from one room to another. Evidence: Some evidence from a restaurant outbreak in China where the air conditioning units created poor distribution and led to viral transmission in a poorly ventilated space. Evidence of incorrect pressurisation in hospital isolation facilities leading to transmission of other airborne viral infections. Evidence from modelling/chamber studies shows influence of in-room distribution, but very little real-world evidence. Practical considerations: Encourage mixing of air in the space when accompanied by fresh air supply. Air circulation devices such as fans can help with avoiding stagnant zones.
	Application of room scale air cleaning/UV devices	Rationale: There is reported evidence to show that room scale UV systems and air filtration devices can reduce the levels of surface and airborne microorganisms in a treated space. Evidence: Evidence for upper-room UV efficacy against TB in real-world settings. Most studies are smaller scale hospital evaluation studies or laboratory based investigations conducted under well controlled conditions. Some related, independent literature reviews have also been undertaken but these are limited in number. Practical considerations: Potential benefits in rooms with poor ventilation which can't be improved otherwise. Devices need to be sized appropriately for the environment. UV systems and some air cleaning technologies have safety considerations. UV treatment is subject to shadowing effects or for ceiling mounted devices the passage of bioaerosols past the fixed UV lamps. This is linked to the energy dose delivery of the system, so devices must be validated against appropriate target microorganisms. Air filtration system efficiency is dependent on air flow rate, achieved air mixing effects and filtration efficiency. Further to this, UV lamps deteriorate over time and must be well maintained to be effective over long periods of use. More detail in EMG paper [F].
	Installation of local exhaust systems or local air cleaning devices	Rationale: It is theoretically feasible to disrupt close range aerosol and droplet transmission using technology such as a local ventilation exhaust or air cleaning devices. Evidence: There is some limited evidence for this in healthcare, such as specialised ventilation systems in operating theatres, however there is not good evidence for application in close range infection control. Practical considerations: Devices are not readily available and their effectiveness will depend significantly on design and positioning. Such approaches may be appropriate to develop for certain high risk locations (e.g. dentistry) but

		are unlikely to currently be a viable approach for most environments. *Research to explore approaches for dentistry should be a priority.*
	Propping open internal doors to enhance airflow	Rationale: Wind driven ventilation can sometimes be enhanced when opposite sides of a building are linked for airflow purposes, and propping doors open can lead to larger ventilation flow rates. Propping such doors open can also reduce contact risks through touching door handles. Evidence: Evidence is very weak Practical considerations: There may be significant barriers in many environments, including fire safety, security thermal comfort and privacy which may undermine the mitigation in practice. The impact is likely to be small. There could be risks from this strategy in high risk environments such as healthcare.
	Personalised ventilation systems	Rationale: Systems provide a clean air stream directly to individuals and hence this reduces exposure to aerosols in the general room air. Evidence: There are several studies that show provision of personalised ventilation (PV) can provide a clean air stream and could mitigate exposure, however these are all modelling/chamber based studies rather than real-world. One study shows that without careful design these systems can facilitate transport of exhaled pathogens and increase indirect exposure. Practical considerations: This is a technology area with future potential for certain environments such as offices, however there is not sufficient development yet for it to likely be a feasible solution. Approach is only effective when people are located by the PV system.
	Use of UV/HPV decontamination	Rationale: Mobile UV and hydrogen peroxide vapour (HPV) systems can reduce surface contamination levels in room spaces of various sizes and have been applied to vehicle use in some cases. Evidence: Most studies are smaller scale hospital evaluation studies or laboratory based investigations conducted under well controlled conditions. Some independent literature reviews have been undertaken but these are limited in number. There is little evidence of recent large scale side by side comparison studies of these devices. Practical considerations: Both UV and HPV treatments are subject to shadowing effects and neither can remove physical soil on surfaces. For UV this is linked to the energy dose that can be delivered to a surface and related line of sight effects. For HPV this is related to mixing and settling of the vapour or mist which may limit treatment of surfaces that are partially hidden or facing away from the delivery system. For these reasons all such devices must be validated against appropriate target microorganisms. There are additional cost, environmental and toxicity issues. More detail is given in EMG paper [F].

	Good maintenance of sanitation/drainage systems	Rationale: Good maintenance and cleaning practices limit aerosolization from toilet flushing and ingress of aerosols from drainage system via defective water trap seals. Cleaning and hygiene practices with inspection and monitoring of water trap seals will limit spread. Evidence: Mechanistic and real-world studies showing aerosolization from toilet flushing and from defective water trap seals. Weak evidence of viral loads in air samples. Some evidence to suggest that higher ventilation rates in bathrooms can encourage aerosols from defects to enter the room and fall on surfaces. Some evidence of surface contamination mainly in hospitals. Probability of transmission low, however increased under defect conditions. Evidence for reducing aerosols from toilet flushing by closing lid before flushing and evidence for reducing spread by contact from enhanced cleaning and disinfection of bathrooms and toilet facilities. Whole system monitoring has been trialled successfully in real-world settings. Practical considerations: Any possibility of virus transmission will be decreased by enhanced cleaning regime. Maintenance of water trap seals (particularly in less visible places such as plant rooms) should be ongoing. Waterless traps in use but not widespread – easy to install. Whole system condition monitoring effective. Particular attention should be paid to this in buildings which have been unused during lockdown.
	Enhanced sunlight in buildings	Rationale: UV in sunlight may help to destroy COVID-19 viruses Evidence: There is evidence that sunlight can be effective against pathogens, and some evidence that it may be effective against COVID-19 viruses, but the studies are based in laboratory test environments. Practical considerations: Double glazing will provide a barrier to UV light, and in most buildings there would be limited sunlight opportunity to enable comprehensive exposure. Simple actions such as keeping blinds open is a low-cost measure that could have a very small benefit but may have negative impacts such as overheating and glare.
Administration	Frequency of high touch surface cleaning	Rationale: Contact transmission from contaminated surfaces could be ameliorated by cleaning of hand touch sites, provided the frequency is sufficient to mitigate the rate of recontamination. Evidence: Good evidence that a range of cleaning agents are effective against the virus. Some evidence to suggest that frequently touched sites in the patient zone should be cleaned once a day in hospital wards; and more often (twice/day; hourly) in critical care. There is evidence to show that sites which are handled most yield higher amounts of microbial soil; the more microbial soil there is at a site, the more likely that there will also be a pathogen. Microbial soil is not necessarily visible. No clear evidence for frequency of cleaning for COVID.

		Practical considerations: Cleaning supervisors can adjust SOPs to increase the frequency of cleaning the highest risk sites in both COVID and non-COVID areas. Provided the 'one site; one wipe; one direction' strategy is employed, surfaces can be effectively cleaned with detergent wipes in healthcare. Bleach may also be used at the appropriate dilution if there is potential heavy contamination of surfaces. Alcohol wipes may be used for some equipment in accordance with manufacturers' guidance.
	Frequency of general room surface cleaning	Rationale: Increased frequency of cleaning general room surfaces may reduce the presence of virus and reduce the risk of contact transmission to staff and visitors. Evidence: Good evidence that a range of cleaning agents are effective against the virus. There is limited evidence for transmission risks via general surfaces – there is more evidence for high touch sites. Practical considerations: Most infection control staff are likely to support increased frequency of room cleaning where there is a high COVID risk. There is a case for ensuring good cleaning generally, with a focus on high touch sites likely to increase effectiveness. The frequency selected may be dependent upon resources.
	Training on quality and effectiveness of cleaning	Rationale: Training the commercial cleaning workforce should result in more effective cleaning. Evidence: Good evidence to support the impact of targeted training for housekeeping staff in hospital environments. There is also evidence to show that this impact quickly wears off and requires repeated educational reinforcement. Practical considerations: Needs appropriate training materials to be developed and effectively disseminated in an organisation. Will need monitoring and may need incentives.
	Provision of hand sanitiser	Rationale: Increasing provision of hand sanitiser may encourage more people to clean their hands and thus reduce the risk of contact spread Evidence: Evidence that sanitiser has an antimicrobial effect, but less effective at removing physical soil. Practical considerations: Generally an easy solution in most settings. Efficacy is dependent on societal and behavioural conditioning on hand hygiene which may change with perceived level of risk. Guidance on hand hygiene is already provided by WHO and others
	Replacement of jet dryers with paper towels	Rationale: Jet air dryers can aerosolise microorganisms from poorly washed hands. Incomplete drying of hands means that contamination can persist on hands.

		Evidence: Mechanistic studies to show microbial dispersion and studies using surrogate microorganisms show persistence of contamination. No direct evidence for transmission. Practical considerations: Relatively easy action to temporarily take dryers out of action and provide paper towels. Need to consider the management of paper towel waste. Longer term there are cost and energy implications.
	Avoid sharing equipment (e.g. IT, hot-desking)	Rationale: Shared surfaces create a route for indirect contact transmission via touch Evidence: Several studies in healthcare environments have shown presence of SARS-CoV-2 virus on shared equipment such as computer mice and keyboards. For other diseases there is evidence that sharing a desk was a factor in transmission. No clear evidence of transmission for COVID, although there are office outbreaks. Practical considerations: Relatively straightforward action but there may be significant resource and space implications in some environments. Where it is not possible to avoid shared equipment, a cleaning regime between users should be implemented.
	Management of waste	Rationale: To limit transmission of SARS-CoV-2 from handling contaminated waste. This is particularly relevant to bathroom waste (paper towels used for drying hands). Evidence: Evidence for the survival of SARS-CoV-2 on different materials for considerable time. No evidence found in the literature for the safe handling of contaminated waste in buildings outside of healthcare settings and chemical contamination settings. BS5906:2005 sets out procedures for handling most types of waste in buildings. Practical considerations: Pragmatic approach required. Areas of concern: Bathroom areas, removal of potentially contaminated paper towels and other items. No evidence in literature around this area. Risk is very low but manual handling of all waste and packaging and use of compactors are possible areas of concern. Warning signage and training for staff required.
	Hygiene behaviours in bathrooms (e.g put the toilet lid down before flushing)	Rationale: Virus could be dispersed in faecal aerosol, bathrooms have multiple high touch surfaces. Both can be modified by behaviour change. Evidence: It is well known that people do not necessarily wash their hands after using the bathroom. There is evidence for reduction in aerosol plumes by closing toilet lid before flushing, although no direct evidence of transmission. Some evidence of contamination of touch surfaces such as door handles and flush activation devices (handles, buttons, no touch controls) - see no touch section for evidence on these.

		Practical considerations: Place the flush behind the toilet seat so that users need to put the seat down to use the flush. Make sure that there are ample quantities of liquid (not bar) soap and disposable paper towels. Notice on the door asking whether the user has washed their hands. While closing the toilet lid will help, it may leave the toilet seat contaminated after a flush. A regime of cleaning the toilet lid before use or at regular intervals throughout the day.
	Changes to touch behaviours (e.g. education programmes)	Rationale: Reducing facial touching is likely to lead to reductions in passing contamination from hand to viral entry points on the face – mouth, nasal passages and eyes. Evidence: The evidence for changing habitual behaviours such as face touching through education programmes shows at best weak effects. More effective approaches include shaping behaviours incompatible with face touching such as keeping hands below shoulder level. Currently there is no evidence on the potential effectiveness of this approach. Practical considerations: It is difficult to change these and other habitual behaviours that often occur without awareness. Simple messaging may have a small effect, but it is unlikely to persist, and adding additional messages of this kind may distract from other messages that have a larger and more reliable effect on reducing infection and transmission.
	Lower density of occupants	Rationale: Reduces probability of an infectious person being present, reduces duration of exposure, enables easier compliance with distancing Evidence: Evidence that transmission is occurring in highly occupied settings where people are in close proximity. Models for transmission show this is an effective measure. Practical considerations: Feasibility will depend on the design and configuration of the environment and the activities that need to be carried out. Settings such as transport are difficult to operate with a lower density. Alternative strategies for work/activities such as remote meeting software, enabling active travel (cycling), limiting time people can spend in a particular location could all assist in enabling this approach.
	Maintain 2m distancing	Rationale: Increased distance reduces the likelihood of exposure to a high viral load through droplets/air and on surfaces close to infectious person. Evidence: Meta-analysis suggests that risk is substantially reduced at 1m and 2m provides a further 2x reduction. Chamber and modelling studies show cough aerosols and droplets are greatly reduced by a distance around 2m from the source. Epidemiological evidence from outbreaks on aircraft show highest risk within 2-3 seat rows.

		Practical considerations: Distancing needs to recognise that people are not static and hence allow leeway for real-world. Challenging to maintain in some environments, in which case additional measures will be needed.
	One-way systems for moving through spaces	Rationale: Enable more effective physical distancing and preventing crowding, particularly in corridor type spaces Evidence: No clear evidence to support that this approach can influence disease risk. There is evidence relating to managing people flow in spaces. Practical considerations: Likely to be most appropriate for settings where there is a risk of crowding such as transport hubs, shops and corridors in schools/busy office environments. Will depend on the physical space available. Needs clear signage and reminders to follow. System needs to be carefully thought through otherwise people are likely to ignore it. May have some impacts on accessibility.
	Orientation of people	Rationale: Locating people to the side or back-to-back reduces close range exposure as people are no longer facing the direct plume or exposed to the high surface concentrations Evidence: There is evidence from modelling and chamber studies that suggests this is beneficial, but there seems to be limited real-world evidence. Practical considerations: Application will depend on the ability to rearrange a particular space and whether this will be effective for the particular circumstances. This approach should also take into account human behaviour and whether people will remain in a position where they don't face each other.
Personal protection	Respirator (N95/FFP3) face masks	Rationale: Significantly reduces exposure to droplets and aerosols where the respirator is fit tested for the wearer and worn properly. Widely used in exposure prone occupations prior to the Sars-CoV-2 pandemic. Evidence: There are many publications over several decades to confirm the effectiveness of well-fitting N95 (FFP2 equivalent) and FFP3 masks at protecting the wearer. This includes a number of comparison studies between different mask types. Practical considerations: Need to be fitted correctly to be effective. Only suitable for aerosol generating procedures in healthcare and other very high risk environments . The effectiveness of these masks must not be confused with surgeon style masks, which are not classed as respiratory protective equipment and are designed to protect others from droplets generated from the mouth and nose of the wearer; these are inefficient at protecting the wearer

		from inhalation of bioaerosols. There are concerns that valved masks could enhance exposure if the wearer is infected.
	Surgical face masks	Rationale: Reduces potential for droplet exposure through reducing amount that reaches nasal membranes/large droplet inspiration. Potentially effective as a source to block the emission of droplets and some aerosols. Reduces the force of respiratory emissions so they will travel shorter distance. Evidence: Several studies show that they are reasonably effective as a source and exposure control. More effective against droplets than aerosols. Evidence is covered in earlier NERVTAG paper, DELVE review and EMG paper (04062020) Practical considerations: Effectiveness depends on material and fit. Biggest impact on effectiveness is likely to be user compliance and wearing properly. Most appropriate for healthcare settings and high exposure risk workplaces.
	Face coverings	Rationale: Potentially effective to block the emission of droplets and some aerosols from a source of infection. Reduces the force of respiratory emissions so they will travel shorter distance. May have a small impact on exposure. Effectiveness will depend on the material and construction. Evidence: Some evidence from measurements with people, mechanistic data from laboratory/modelling shows materials can block a proportion of droplets and aerosols. Face coverings are detailed in earlier NERVTAG paper and a DELVE review. Practical considerations: Mechanistic effectiveness depends on material and fit. Important to consider user compliance, wearing properly, and hygiene aspects of face coverings.
	Gloves	Rationale: Wearing gloves can reduce the likelihood of contamination on hands Evidence: Standard PPE in healthcare, to prevent transmission from healthcare worker to patient and vice versa, however only effective where gloves are discarded afterwards. No evidence from community settings. Laboratory studies show that gloves can become contaminated and could therefore present a transmission risk to others. Practical considerations: People who wear gloves feel themselves to be protected and may miss opportunities for hand hygiene. Gloves can pose a transmission risk where they are worn in multiple environments. They should only be recommended for high risk settings with a proper protocol for use.
	Protective clothing (personal protective equipment [PPE])	Rationale: There is evidence that protective gowns, overalls and gloves will offer the wearer physical barrier protection from droplet splash and other contaminated bodily fluids and waste.

		Evidence: The performance quality and safety standards required for these items are underpinned internationally by a series of BS EN and ISO standard tests and within the UK only approved test houses can provide such test reassurances. Such tests provide evidence of fitness for purpose. Practical considerations: Fit, wearer comfort, including thermal comfort, requirements for manual dexterity may prevent the use of some types of PPE, acceptability to others who interact with the wearer. Donning and doffing of protective clothing is important and wearer contamination may occur during doffing if not done with care. Usage is only likely to be appropriate in a high risk environment.
	Face shields/goggles	Rationale: Reduces potential for droplet exposure through eyes for goggles and nasal membranes and large droplet inspiration for shields. Very limited effect on aerosol exposure. Evidence: No evidence as source control, some evidence from mechanistic studies and one small study with human challenge that suggests they are quite effective to prevent exposure. This is reflected in a recent meta-analysis. The performance quality and safety standards required for these items are underpinned internationally by a series of BS EN and ISO standard tests and within the UK only approved test houses can provide such test reassurances. Such tests provide evidence of fitness for purpose, including face, side of face protection and visual distortion effects Practical considerations: Relatively straightforward approach, but only likely to be appropriate for people who are at high risk of exposure and/or will struggle to maintain physical distancing. Fit, wearer comfort, including thermal comfort, requirements for good visibility may prevent the use of some visors/goggles, acceptability to others who interact with the wearer. As with protective clothing, visor/face shield removal technique is important where significant contamination is encountered and wearer contamination may occur during doffing if not done with care.

SAGE papers referenced

[A] Evidence of environmental dispersion for COVID-19 for different mechanisms, SAGE paper 14th April 2020

[B] Environmental influence on transmission, SAGE-EMG paper, 28th April

[C] Using understanding of transmission routes to inform risk assessment and mitigation strategies, SAGE-EMG paper, 14th May 2020

[D] EMG-Survival of SARS-CoV-2 in the Environment, SAGE-EMG paper, 12th May 2020

[E] EMG: Transmission and Control of SARS-CoV-2 on Public Transport + repository paper, SAGE-EMG paper, 18th May 2020

[F] EMG: Summary of disinfection technologies for microbial control + repository paper, SAGE-EMG paper, 18th May 2020

[G] EMG: Evidence for mitigation measures for reducing the exposure to SARS-CoV-2, SAGE repository, 4th June 2020

References

[1] C. Xu, X. Luo, C. Yu, and S. J. Cao, "The 2019-nCoV epidemic control strategies and future challenges of building healthy smart cities," *Indoor Built Environ.*, vol. 29, no. 5, pp. 639–644, 2020, doi: 10.1177/1420326X20910408.

[2] J. Wei and Y. Li, "Enhanced spread of expiratory droplets by turbulence in a cough jet," *Build. Environ.*, vol. 93, no. P2, pp. 86–96, 2015, doi: 10.1016/j.buildenv.2015.06.018.

[3] W. Chen, N. Zhang, J. Wei, H. Yen, and Y. Li, "Short-range airborne route dominates exposure of respiratory infection during close contact," *Build. Environ.*, pp. 1–33, 2020, doi: 10.1016/j.buildenv.2020.106859.

[4] D. K. Chu *et al.*, "Articles Physical distancing , face masks , and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19 : a systematic review and meta-analysis," vol. 6736, no. 20, 2020.

[5] X. He *et al.*, "Temporal dynamics in viral shedding and transmissibility of COVID-19," *Nat. Med.*, vol. 26, no. May, 2020, doi: 10.1038/s41591-020-0869-5.

[6] P. Y. Chia *et al.*, "Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients.," *Nat. Commun.*, vol. 11, no. 1, p. 2800, 2020, doi: 10.1038/s41467-020-16670-2.

[7] Q. Bi *et al.*, "Epidemiology and transmission of COVID-19 in 391 cases and 1286 of their close contacts in Shenzhen, China: a retrospective cohort study," *Lancet Infect. Dis.*, vol. 3099, no. 20, pp. 1–9, 2020, doi: 10.1016/S1473-3099(20)30287-5.

[8] P. Little *et al.*, "Reducing risks from coronavirus transmission in the home-the role of viral load," *BMJ*, vol. 369, no. May, p. m1728, 2020, doi: 10.1136/bmj.m1728.

[9] Y. Il Kim *et al.*, "Infection and Rapid Transmission of SARS-CoV-2 in Ferrets," *Cell Host Microbe*, vol. 27, no. 5, pp. 704-709.e2, 2020, doi: 10.1016/j.chom.2020.03.023.

[10] S. F. Sia *et al.*, "Pathogenesis and transmission of SARS-CoV-2 in golden hamsters," *Nature*, 2020, doi: 10.1038/s41586-020-2342-5.

[11] L. Bao *et al.*, "Transmission of SARS-CoV-2 via close contact and respiratory droplets among hACE2 mice," *J. Infect. Dis.*, May 2020, doi:

10.1093/infdis/jiaa281.

[12] L. Hamner *et al.*, “High SARS-CoV-2 Attack Rate Following Exposure at a Choir Practice — Skagit County, Washington, March 2020,” *MMWR. Morb. Mortal. Wkly. Rep.*, vol. 69, no. 19, pp. 606–610, 2020, doi: 10.15585/mmwr.mm6919e6.

[13] R. Pung *et al.*, “Investigation of three clusters of COVID-19 in Singapore: implications for surveillance and response measures,” *Lancet*, vol. 395, no. 10229, pp. 1039–1046, 2020, doi: 10.1016/S0140-6736(20)30528-6.

[14] J. Cai, W. Sun, J. Huang, M. Gamber, J. Wu, and G. He, “Indirect Virus Transmission in Cluster of COVID-19 Cases, Wenzhou, China, 2020,” vol. 26, no. 6, pp. 1343–1345, 2020.

[15] F. Xiao *et al.*, “Infectious SARS-CoV-2 in Feces of Patient with Severe COVID-19.,” *Emerg. Infect. Dis.*, vol. 26, no. 8, pp. 1–5, 2020, doi: 10.3201/eid2608.200681.

[16] Y. Feng, T. Marchal, T. Sperry, and H. Yi, “Influence of wind and relative humidity on the social distancing effectiveness to prevent COVID-19 airborne transmission: A numerical study.,” *J. Aerosol Sci.*, vol. 147, no. April, p. 105585, 2020, doi: 10.1016/j.jaerosci.2020.105585.

[17] T. Dbouk, D. Drikakis, and) Affiliations, “On coughing and airborne droplet transmission to humans Physics of Fluids ARTICLE scitation.org/journal/phf On coughing and airborne droplet transmission to humans,” *Phys. Fluids*, vol. 32, no. April, p. 53310, 2020, doi: 10.1063/5.0011960.