EMG-Nervtag Update on Transmission and Environmental and Behavioural Mitigation Strategies, including in the context of Delta

This paper considers the most recent evidence relating to transmission of SARS-CoV-2 and the implications for the effectiveness of environmental and behavioural mitigation strategies. The paper draws primarily on published evidence from epidemiological studies, animal studies, viral emission measurements and modelling studies. While there is still limited published evidence relating specifically to the Delta variant, the paper considers the implications of this more transmissible variant from the perspective of mitigation.

While this paper focuses primarily on environmental and behavioural mitigations that can be applied in different settings these must continue to be applied alongside a range of other strategies including working from home; an effective programme of testing, tracing, and isolating; and vaccination. The environmental and behavioural strategies described in this paper act to reduce the risk of exposure within a setting, but do not change the probability of an infected person being present in a setting. In the context of Autumn 2021 these other strategies are predominately considered in other papers, and this paper should be read in conjunction with them [A, B].

Executive summary

Transmission can happen through close range exposure to aerosols and droplets, exposure to aerosols in air, and/or via contaminated surfaces (fomites). Inhalation at close range or in shared indoor air is a more likely route of transmission than via fomites, however all routes of transmission are possible and should be mitigated. A risk assessment approach that considers all activities and modes of transmission remains an important step in managing transmission for all variants (high confidence)

<u>Transmissibility and modes of transmission</u>

- The Delta variant is more transmissible than previously identified variants (*high confidence*).

- Vaccination has been shown to be one of the most effective strategies in managing the pandemic, being highly effective at reducing the risk of severe disease and death and reducing transmission (*high confidence*). Compared to other variants that have circulated widely in UK, such as Alpha, Delta is less sensitive to inhibition by neutralising antibodies. Therefore, prior SARS-CoV-2 infection or vaccination provides less protection against infection with Delta than against previous virus variants (*high confidence*).

- Fully vaccinated people who are infected with the Delta variant may have as high a viral load as those who are unvaccinated (high confidence) A vaccinated person who is infected may be as likely to transmit virus to others as an unvaccinated person (*high confidence*). Environmental and behavioural mitigations are therefore still needed to manage the Delta variant even in settings where there is high vaccine coverage. This should be considered in the context of any risk management strategy (*high confidence*).

- The most commonly reported symptoms of Delta are still cough, fatigue and headache, but symptoms are more likely to be mild in vaccinated cases and may be harder to

distinguish from the common cold. This may increase the likelihood for onward transmission by undiagnosed vaccinated cases (*medium confidence*)

- There is no evidence that the fundamental mechanisms of transmission are different with the Delta variant, however a higher viral load (for example as indicated by Ct values that reflect viral RNA levels in a sample) may mean that more virus is emitted by an infectious person and transmission can happen more readily (*medium confidence*). Modelling suggests that all modes of transmission remain important but the importance of different modes of transmission could change with a more infectious variant for certain scenarios. It may be the case that long range airborne transmission could happen more frequently and that the infection risk per unit time of exposure could be higher at both close range and in shared air (*medium confidence*). There is currently insufficient data to quantify this with any certainty for the Delta variant.

- There is some evidence from studies of human SARS-CoV-2 viral emission rates, animal models and air sampling that there may be proportionally more virus within fine aerosols (<5 μm) than larger aerosols for all virus variants (*medium confidence*). A small amount of data from human and animal models suggests some variants, including Alpha and Delta, may result in higher viral aerosol emissions (*low confidence*). These further add to the evidence base for the importance of aerosol transmission at both close range and long range (>2m), and the potential for aerosol transmission to be more important for more transmissible variants including Delta (*medium confidence*).

- Measured viral emission levels for all variants increase significantly during talking and singing activities. This is consistent with previous studies that have measured aerosol particles (but not virus) and is also consistent with reports of large super-spreading events associated with talking, singing or aerobic activity (*high confidence*).

- Some data from animal models suggests that the severity of infection could increase with higher exposure dose, and therefore mitigations that reduce exposure to the virus could reduce severity as well as overall transmission (*low confidence*)

<u>Environmental and Behavioural Mitigations</u>

- There is no strong evidence to suggest that fundamentally different mitigations are required against the Delta variant, but mitigations may be less effective against the Delta variant than previous variants (*medium confidence*). There is a small amount of evidence suggesting that large outbreaks of the Delta variant can happen in settings where some mitigations have been applied, but the level of mitigation that this entails is unclear. There is also evidence that some other countries (e.g. New Zealand, Vietnam, Japan) which have previously managed outbreaks well are finding the Delta variant more challenging to control using a level of mitigations that was effective with previous variants.[1]

- It is important that consideration is always given to each route of exposure and each activity undertaken using mitigations selected which are appropriate for the specific circumstances and are based on a hierarchy of risk controls. The increased transmissibility of the Delta variant, and possibility for higher probability of airborne

[1] A clarification to wording has been made to this paragraph to reinforce that the level of mitigations applied and what this entails are unclear.

transmission, should be considered when any risk assessment is undertaken or reviewed. The risk assessment should also consider the individual and population risks, including particular risks or vulnerabilities in the population of people concerned (*high confidence*).

- Maintaining an emphasis on applying measures consistently and effectively is particularly important given that we are heading into Autumn with high prevalence of infection and that changes in the weather and dark evenings mean people are more likely to mix indoors, in some cases with poor ventilation (*medium confidence*).

- Tackling unmitigated or poorly mitigated settings is likely to give more benefit than applying more stringent environmental guidelines (e.g around ventilation rates) to those settings which have already applied good control measures (*medium confidence*).

- Mitigations need to be applied together; enhancing one measure such as ventilation cannot fully compensate for the removal of other measures, especially if they address different transmission routes. There are no silver bullets. (*high confidence*).

- Environmental and behavioural interventions that are likely to be most effective remain as previously indicated (in no particular order):
    - Ensuring good airflow by interacting outdoors and improving poor indoor ventilation can mitigate airborne transmission (*high confidence*). Strategies such as HEPA or UV-C based air cleaners may be beneficial particularly when it is not possible to provide sufficient indoor ventilation (*medium confidence*).
    - Maintaining a greater distance between people can mitigate direct exposure to aerosols and droplets at close range where they are more concentrated (*high confidence*). Consideration and avoidance of small spaces or close interactions remains important. It is likely to be beneficial to reiterate the importance of physical distancing even in settings where restrictions on numbers of people have been removed.
    - Promoting high levels of wearing face coverings or face masks can potentially reduce transmission through all transmission routes, especially via close range and long-range airborne transmission (*high confidence*). This is covered separately in the SAGE Plan B paper [A].
    - Ensuring good hand and respiratory hygiene, limiting face touching and using face coverings are likely to reduce the small risks of fomite transmission. As transmission via surfaces is most likely to occur in a short time period following contamination, hand and respiratory hygiene is likely to be more effective than enhanced cleaning in most settings (*medium confidence*).

- Effective mitigation requires individuals and organisations to understand the reasons that particular mitigations are being selected for specific activities and specific routes of exposure, clear guidance on what to do and when, and effective messaging and regulatory approaches to ensure mitigations are applied in line with agreed guidance (*high confidence*).

Evidence summary

<u>Epidemiological evidence around Delta transmissibility and transmission</u>

There is evidence that viral load is higher for Delta variant. An outbreak investigation in China (pre-print) involving 167 cases suggested viral loads were around 1000 times higher on the day when infections were detected[1], however it is possible that this was influenced by the investigation methodology. An analysis of results from 738 COVID-19 patients in France assessed relative viral load (VL) from CT values (for ORF1ab and N target genes) [2]. For the ORF1ab target gene, the Delta variant presented a VL ten times higher than the historical variants (median 7.83 log10 copies/ml). A two-fold difference was also observed between the Delta variant and the Alpha and Beta variants. For the N gene, the Delta variant presented a 5-fold higher VL than the historical variants, and a 2.5-fold higher difference was observed in VL levels between the Delta variant and the Beta variant; the Alpha and Delta variants had similar VL.

Although vaccination reduces the chance of infection with SARS-CoV-2, analysis has shown that people with Delta infections after two vaccine doses had similar peak viral loads to those in unvaccinated people[3], [4]; with the Alpha variant, peak viral loads in those infected post-vaccination were much lower [3]. A recent household study also found similar peak viral loads between vaccinated and unvaccinated people, and those who were vaccinated and infected with the Delta variant were as likely to transmit virus to others in the household and can be an index case in an unvaccinated household. The secondary attack rate for full-vaccinated contacts exposed to Delta was19.7% (95%CI:11.6-31.3%), compared with 35.7% (95%CI:16.4-61.2%) in the unvaccinated [5]. An outbreak in a prison where physical distance is challenging affected 74% of 233 prisoners, with a higher rate 39/42 (93%) among unvaccinated compared to vaccinated 129/185 (70%). The most severe cases were among the unvaccinated group [6].

Secondary attack rates with Delta in the week commencing 16th August 2021 amongst household contacts were estimated at 11.4% (95% CI: 11.2-11.6%) and non-household contacts at 4.9% (95% CI: 4.6%-5.2%) [7].

Some superspreading outbreak reports with the Delta variant are reported with high secondary attack rates and despite mitigations being in place. An outbreak in a school in the US [8] reported transmission from a symptomatic teacher over 2 days to 50% of children in a class, with higher numbers in the front row nearest to the teacher. Six-foot distancing between desks and mask mandates were in place for pupils and teacher, but the teacher removed her mask to read out loud. The investigation reports that windows/doors were open and a HEPA air filter was present, but there is no data on effectiveness of these measures. It is also unclear how people interacted in the classroom. An outbreak in a hospital in Finland [9] reported symptomatic and asymptomatic infections among vaccinated HCW and secondary transmission. The study reports that droplet and contact precautions were applied, with surgical face masks and face shields used when caring for COVID-19 patients, and suggests that moving to FFP2 respirators when HCW were in close contact with a confirmed case was successful in controlling the outbreak[2]. However the level of application of measures such as surgical masks for undiagnosed cases is unclear and the nature of the testing regime may have contributed to the lack of detection of cases.[3] A similar outbreak was reported at a hospital in Israel [10], where rapid nosocomial spread led to 42 cases. This occurred from one individual to 15 other patients, 9 staff and two family members, with then secondary spread likely from an infected healthcare worker to 9 further staff, 8 patients

[2] A clarification to wording in this sentence has been made to expand upon the ways in which droplet and contact precautions were applied.

[3] An additional sentence has been added to clarify that the level of application of measures is unclear and that the testing regime may have impacted detection.

and one family member. The attack rate among all exposed patients and staff was 10.6% for staff and 23.7 % for patients in a population with a 92.6% vaccination rate (Comirnaty vaccine). Several transmissions probably occurred between two individuals both wearing surgical masks, and in one instance using full PPE, including N-95 mask, face shield, gown and gloves.

It is difficult to determine how representative these large outbreak cases are, or whether there is bias towards reporting more extreme outbreaks rather than smaller outbreaks. These three large reported outbreaks occurred when some (but not all) control measures had been applied, while many of the large outbreaks early in the pandemic highlighted the absence of control measures or poor adherence to control measures. This suggests that it may be harder to contain the Delta variant with environmental and behavioural control measures particularly if they are incomplete or there is reduced adherence to these measures, and such measures need to be applied with greater rigour and well communicated to the individuals who are required to use them.[4]

In August 2021 58% of people testing positive for COVID-19 in the UK with a strong positive test reported symptoms, which has increased since March 2021 and is similar to levels seen in January and February 2021. This is potentially because of a higher average viral load in June and July 2021 compared with March 2021. Symptoms reported were more likely to be "classic" symptoms than gastrointestinal or loss of taste or smell only. The prevalence of “classic” and any symptoms was generally higher in June and July, and January and February, compared with March and April where prevalence was lower. This is consistent with higher average viral load in January, February, June and July 2020 [11]. The most commonly reported symptoms of Delta are still cough, fatigue and headache, but symptoms are more likely to be mild in vaccinated cases and may be harder to distinguish from the common cold.

There is also evidence that there are differences in reinfection cases for Delta. Previously reinfections were milder, i.e. lower viral load (higher Ct values) and less likely to have symptoms [31]. Since Delta, this is no longer the case and there is no longer a significant difference between median (or IQR) Ct values between index positives and reinfections and no longer a difference in symptoms within 35 days of the first positive in the episode [32].

Recent evidence around mechanisms for SARS-CoV-2 transmission

Virus in exhaled breath: Two recently published studies [12], [13] have measured viral RNA directly from human exhaled breath using an approach that can size fractionate into fine aerosols (<5 micron diameter), large aerosols (likely 5-20 micron diameter), and in one of the two studies fomite (aerosols/droplets that deposit out prior to sampling). Both studies show a higher proportion of viral RNA in fine aerosols than previously estimated.

The first study from a group in Singapore [12] measured detectable levels of RNA in 13/22 (59%) of PCR positive participants. Participants were measured during breathing, talking and singing. 6 participants emitted detectable levels during all activities, however 4 only emitted during singing or talking. Only 2 patients coughed; one emitted and the other didn’t have detectable RNA. Emission rates varied between 63 and 5821 RNA copies per activity per participant and very high person-person variation and an increase in emissions with talking and singing. Patients with detectable RNA were earlier in the course of illness (day 3 vs 5), and the two highest emitters responsible for 52% of the total viral load measured across all participants were both sampled on day 3; this aligns with several other studies that

[4] Clarifications to wording have been made in this paragraph to reflect the certainty of the measures impact.

indicate that a small number of people are likely to be responsible for a large proportion of infections. Fine aerosols comprised 85% of the total viral load detected, which is a higher proportion than would be expected if the virus was evenly distributed by volume in respiratory emissions. However it is possible that the relative fraction of virus in different size distributions is influenced by the sampling techniques and recovery efficiency at different sizes. Talking and singing significantly increased viral emissions compared to breathing alone, as shown in Table 1 below. 16/22 participants were infected with a Variant of Concern (1 Delta), but there were insufficient numbers for each variant to determine whether there were differences in viral shedding.

Table 1: Median viral RNA loads reproduced from Coleman et al 2021 indicating variation in emissions with activity

	Breathing	Talking	Singing	*P*
Total number	63.5 (0–227.6)	477.9 (234.5–135.6.5)	713.6 (135.2–1216.1)	.026
Fine fraction	0 (0–0)	417.0 (191.2–979.5)	366.4 (93.9–1078.1)	.013
Coarse fraction	0 (0–159.9)	0 (0–77.8)	38.4 (0–508.4)	.36

All values expressed as viral N gene copies per expiratory activity (30-minutes breathing, 15-minutes talking, 15-minutes singing) in median (interquartile range). n = 13. Medians across 3 groups were compared using Kruskal-Wallis test.

A second study [13] using the same method of measuring viral emissions recruited 61 PCR positive people, 49 of whom were known seronegative. The majority of participants were infected with the original variants, however 4 participants had the Alpha variant (none were infected with Delta). Viral RNA was detected in 45% of fine (≤5 μm), 31% of coarse (>5 μm) aerosols, and 65% of fomite samples overall including in all samples from four Alpha-variant cases. Participants spoke or sung and wore either a surgical mask or their own mask/face covering and these reduced fine aerosol by 48% (95% confidence interval [CI], 3 to 72%) and coarse by 77% (95% CI, 51 to 89%). Participants with the Alpha variant had significantly higher viral emissions compared to earlier B1.1 like strains. Virus was cultured from fine aerosol from 2/141 of the samples (one Alpha, one Nextstrain clade 20G), both of which were samples from participants who were wearing masks at the time; all coarse aerosol and fomite samples were culture negative. Subjects were typically several days after symptom onset and hence the most contagious period is unlikely to have been measured.

Animal models: Two recent hamster studies show very efficient airborne transmission. A pre-print study with the Alpha variant and lineage A variant [14] shows 8/8 transmission (4 for each variant) at a distance of 2m between cages after 24 hour exposure. Particle measurement prior to the study to verify aerosol behaviour shows that at 2m only those particles <5 μm diameter traversed between cages (>95% of 5-10 μm particles did not traverse and no particles >10 μm were found in the sentinel cage). With just a 1 hour exposure the study shows Alpha (3/4 cases) outcompeting the lineage A variant (2/4 cases) suggesting lower infectious dose. A second study suggests that hamsters are susceptible through intranasal (8×10^4 $TCID_{50}$), fomite (8×10^4 $TCID_{50}$) and aerosol (1.5×10^3 $TCID_{50}$) exposure, with intranasal and aerosol inoculation associated with more severe illness and earlier onset of viral shedding than fomite exposure [15].

A non-human primate study [16] with animals exposed by aerosol also suggests a relationship between infectious dose and disease severity. The median dose for seroconversion (52 TCID50 (95% CI: 23–363 TCID50)) and was significantly lower than the median dose for fever (256 TCID50, 95% CI: 102–603 TCID50). Virus was detected by swabs in a subset of the group of animals who didn't develop clinical signs of disease suggesting that asymptomatic infections could potentially be infectious. The authors highlight those measures which reduce the received exposure dose could minimise the severity of disease in humans.

Virus in the environment: A number of further studies have measured viral RNA in the environment, usually on surfaces. A systematic review of contamination in workplaces suggests higher detectable air contamination is associated with surface contamination, suggesting a link to deposition [17]. A study on banknotes suggests that transmission via contact with cash is unlikely as it would require very high viral loads and events to happen in the right sequence [18]. Further study of viral stability on surfaces confirms earlier findings that viral RNA is most stable on non-porous surfaces [19]. Although RNA can be detected on surfaces for up to 3 weeks, the expected levels of viable SARS-CoV-2 surface contamination from the Ct values obtained from environmental sampling data would lead to undetectable levels within short periods of time (i.e. two days) and hence presence of RNA on surfaces is more likely to be a marker of past contamination rather than an indicator of viable virus even at low CT threshold values. The spatial variation in surface contamination may make it very difficult to detect the highest levels of contamination. Another study showed no significant differences in surfaces stability between variants (Alpha, beta and England) [20]. An unpublished study by the same group (UKHSA) has shown no difference in the surface stability of the Delta variant at room temperature

Two recent studies have sampled air in the vicinity of infected people, both using size fractionation. A study in a healthcare setting detected SARS-CoV-2 RNA (original variant) in all samples and successfully cultured virus from three sub-micron aerosol samples [21]. A study of two volunteers in residential settings indicated a CT value of 38 for one participant indicating a very low amount of airborne virus, but air and surface (mobile phone) samples for the other participant had much lower CT values indicating active shedding. Culture of virus was unsuccessful [22], however a small number of previous studies have detected viable virus on surfaces.

A small number of new studies provide further evidence that aerosol transmission between two spaces can occur. This includes room-to-room transmission in a quarantine hotel that was likely due to continuous flow between the room of the index case and secondary case due to ventilation pressure differences [C] and a study that shows vertical transmission between two apartments in a high-rise block that was associated to drainage stacks [23].

Recent evidence on mitigations

A substantial amount of information on the principles behind different mitigation strategies has been set out in previous papers including:

- Ventilation [D], air cleaning [E], and CO2 monitoring [F]
- Screens and barriers [G]
- Physical distancing and face coverings [H]

An updated paper on the use of face coverings, including some context around the Delta variant is also covered in a companion paper [A].

Here we focus on new evidence relating to the effectiveness of mitigations and evidence relating to application of mitigation measures applied in combination. As highlighted above, there is some evidence that transmission happens at scale for the Delta variant even when mitigations appear to have been applied. There is no quantitative analysis of the quality of the mitigations and how well they were implemented in these studies, but they provide some indication that the Delta variant may be harder to mitigate.

A number of studies provide new evidence to support the importance of enabling effective ventilation strategies, including the use of air cleaning devices to boost the effective ventilation in a room; none of these focus on the Delta variant. A recent small-scale study (pre-print) [24] suggests that the application of portable air filtration devices in a repurposed COVID ward and surge ITU (both relatively poorly ventilated) were effective at reducing the concentration of SARS-CoV-2 viral RNA in the air as well as reducing the concentration of other microbial bioaerosols in the air. The study does not relate the reduction in airborne contamination to any changes in infection risk, as this requires a significantly larger and longer study. However, it provides evidence that air filtration devices may be effective at reducing airborne viral concentrations. A NIOSH led study [25] using surrogate particles also suggests that the use of portable filtration devices can be very effective at reducing exposure to experimentally simulated aerosol emissions. Modelling and mechanistic studies suggest ventilation and air cleaning interventions are likely to be effective, with combined interventions using ventilation and masks together most beneficial [26], [27]. While it is hard to determine the real-world effectiveness of many of these interventions, these modelling and mechanistic studies give further support to the use of these strategies, particularly in poorly ventilated spaces.

A small number of studies provide further evidence that transmission may be influenced by temperature and humidity. A study analysing the first wave of the outbreak in Buenos Aires identified that cases increased as relative humidity decreased, with a lag of around 9 days between the meteorological observation and the positive case reports [28]. A study from the US show that while population mitigation strategies such as lockdown and restricted mobility have the greatest impact on transmission rates, lower temperatures and higher population densities are correlated with increased transmission[29]. An analysis of outbreaks in meat processing plants in Germany [30] found an association between lower ventilation, lower temperature and reduced physical distance and the odds of testing positive for COVID-19. While these studies are not fully conclusive, they further add to evidence that lower temperature and lower humidity conditions, as experienced during winter months, may increase transmission risks.

References

Previous SAGE papers

[A] Considerations for potential impact of Plan B measures, 14th Oct 2021

[B] SPI-B Behavioural considerations for maintaining or reintroducing behavioural interventions and introducing new measures in Autumn 2021, 14th Oct 2021

[C] EMG/Transmission Group/SPI-B: COVID-19 Transmission in Hotels and Managed Quarantine Facilities (MQFs), 9 September 2021 https://www.gov.uk/government/publications/emg-covid-19-transmission-in-hotels-and-managed-quarantine-facilities-mqfs-9-september-2021

[D] EMG: Role of ventilation in controlling SARS-CoV-2 transmission, 30 September 2020 https://www.gov.uk/government/publications/emg-role-of-ventilation-in-controlling-sars-cov-2-transmission-30-september-2020

[E] EMG: Potential application of air cleaning devices and personal decontamination to manage transmission of COVID-19, 4 November 2020 https://www.gov.uk/government/publications/emg-potential-application-of-air-cleaning-devices-and-personal-decontamination-to-manage-transmission-of-covid-19-4-november-2020

[F] EMG and SPI-B: Application of CO2 monitoring as an approach to managing ventilation to mitigate SARS-CoV-2 transmission, 27 May 2021 https://www.gov.uk/government/publications/emg-and-spi-b-application-of-co2-monitoring-as-an-approach-to-managing-ventilation-to-mitigate-sars-cov-2-transmission-27-may-2021

[G] EMG: Role of screens and barriers in mitigating COVID-19 transmission, 1 July 2021 https://www.gov.uk/government/publications/emg-role-of-screens-and-barriers-in-mitigating-covid-19-transmission-1-july-2021

[H] EMG: Application of physical distancing and fabric face coverings in mitigating the B117 variant SARS-CoV-2 virus in public, workplace and community, 13 January 2021 https://www.gov.uk/government/publications/emg-application-of-physical-distancing-and-fabric-face-coverings-in-mitigating-the-b117-variant-sars-cov-2-virus-in-public-workplace-and-community

Published literature

[1] B. Li *et al.*, “Viral infection and transmission in a large, well-traced outbreak caused by the SARS-CoV-2 Delta variant,” *medRxiv*, p. 2021.07.07.21260122, 2021, [Online]. Available: https://www.medrxiv.org/content/10.1101/2021.07.07.21260122v2%0Ahttps://www.medrxiv.org/content/10.1101/2021.07.07.21260122v2.abstract.

[2] E. Teyssou *et al.*, “The Delta SARS-CoV-2 variant has a higher viral load than the Beta and the historical variants in nasopharyngeal samples from newly diagnosed COVID-19 patients,” *J. Infect.*, vol. 83, no. 4, pp. e1–e3, 2021, doi: 10.1016/j.jinf.2021.08.027.

[3] K. B. Pouwels *et al.*, “Impact of Delta on viral burden and vaccine effectiveness against new SARS-CoV-2 infections in the UK,” *medRxiv*, p. 2021.08.18.21262237, 2021, [Online]. Available: http://medrxiv.org/content/early/2021/08/24/2021.08.18.21262237.abstract.

[4] K. K. Riemersma *et al.*, “Shedding of Infectious SARS-CoV-2 Despite Vaccination,” *medRxiv*, p. 2021.07.31.21261387, 2021, [Online]. Available: https://www.medrxiv.org/content/10.1101/2021.07.31.21261387v4%0Ahttps://www.medrxiv.org/content/10.1101/2021.07.31.21261387v4.abstract.

[5] A. Singanayagam *et al.*, “Community Transmission and Viral Load Kinetics of SARS-CoV-2 Delta (B.1.617.2)Variant in Vaccinated and Unvaccinated Individuals,” *Lancet, Accept.*, vol. 39, pp. 1–28, 2021, doi: 10.2139/ssrn.3918287.

[6] L. M. Hagan, D. W. Mccormick, C. Lee, S. Sleweon, L. Nicolae, and T. Dixon, “Outbreak of SARS-CoV-2 B . 1 . 617 . 2 (Delta) Variant Infections Among Incarcerated Persons in a Federal Prison — Texas , July – August 2021,” vol. 70, no. 38, pp. 1349–1354, 2021.

[7] Public Health England, “SARS-CoV-2 variants of concern and variants under investigation in England,” *Sage*, no. April, pp. 1–50, 2021.

[8] M. County *et al.*, “Outbreak Associated with SARS-CoV-2 B . 1 . 617 . 2 (Delta) Variant in an,” vol. 70, no. June, pp. 22–27, 2021.

[9] I. Hetemäki *et al.*, “An outbreak caused by the SARS-CoV-2 Delta variant (B.1.617.2) in a secondary care hospital in Finland, May 2021,” *Eurosurveillance*, vol. 26, no. 30, pp. 1–6, 2021, doi: 10.2807/1560-7917.ES.2021.26.30.2100636.

[10] P. Shitrit, N. S. Zuckerman, O. Mor, B.-S. Gottesman, and M. Chowers, “Nosocomial outbreak caused by the SARS-CoV-2 Delta variant in a highly vaccinated population, Israel, July 2021,” *Eurosurveillance*, vol. 26, no. 39, 2021, doi: 10.2807/1560-7917.es.2021.26.39.2100822.

[11] ONS, “Coronavirus (COVID-19) latest insights: Infections,” 2021. [Online]. Available: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/articles/coronaviruscovid19latestinsights/infections#symptoms.

[12] K. K. Coleman *et al.*, “Viral Load of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) in Respiratory Aerosols Emitted by Patients With Coronavirus Disease 2019 (COVID-19) While Breathing, Talking, and Singing,” *Clin. Infect. Dis.*, vol. 2, no. Xx, pp. 1–7, 2021, doi: 10.1093/cid/ciab691.

[13] O. O. Adenaiye *et al.*, “Infectious SARS-CoV-2 in Exhaled Aerosols and Efficacy of Masks During Early Mild Infection,” *Clin. Infect. Dis.*, pp. 1–35, Sep. 2021, doi: 10.1093/cid/ciab797.

[14] V. J. Port, Julia R; Yinda, Claud Kwe; Avanzato, Victoria A; Schulz, Jonathan E; Holbrook, Myndi G; van Doremalen, Neeltje; Shaia, Carl; Fischer, Robert J; Munster, “Increased aerosol transmission for B.1.1.7 (alpha variant) over lineage A variant of SARS-CoV-2,” *bioRxiv Prepr.*, pp. 12–26, 2020, doi: doi.org/10.1101/2021.07.26.453518.

[15] J. R. Port *et al.*, “SARS-CoV-2 disease severity and transmission efficiency is increased for airborne compared to fomite exposure in Syrian hamsters,” *Nat. Commun.*, vol. 12, no. 1, pp. 1–15, 2021, doi: 10.1038/s41467-021-25156-8.

[16] P. A. Dabisch *et al.*, “Seroconversion and fever are dosepependent in a nonhuman primate model of inhalational COVID-19,” *PLoS Pathog.*, vol. 17, no. 8, pp. 1–19, 2021, doi: 10.1371/journal.ppat.1009865.

[17] J. W. Cherrie *et al.*, “Contamination of Air and Surfaces in Workplaces with SARS-CoV-2 Virus: A Systematic Review,” *Ann. Work Expo. Heal.*, no. July, pp. 879–892, 2021, doi: 10.1093/annweh/wxab026.

[18] D. Todt *et al.*, “A realistic transfer method reveals low risk of SARS-CoV-2 transmission via contaminated euro coins and banknotes,” *iScience*, vol. 24, no. 8, 2021, doi: 10.1016/j.isci.2021.102908.

[19] S. Paton *et al.*, “Persistence of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Virus and Viral RNA in Relation to Surface Type and Contamination Concentration,” *Appl. Environ. Microbiol.*, vol. 87, no. 14, Jun. 2021, doi: 10.1128/AEM.00526-21.

[20] T. Pottage *et al.*, “A comparison of persistence of SARS-CoV-2 variants on stainless steel,” *J. Hosp. Infect.*, vol. 114, pp. 163–166, 2021, doi: 10.1016/j.jhin.2021.05.015.

[21] J. L. Santarpia *et al.*, “The size and culturability of patient-generated SARS-CoV-2 aerosol,” *J. Expo. Sci. Environ. Epidemiol.*, no. March, pp. 5–10, 2021, doi: 10.1038/s41370-021-00376-8.

[22] S. Nannu Shankar *et al.*, “SARS-CoV-2 in residential rooms of two self-isolating persons with COVID-19,” *J. Aerosol Sci.*, vol. 159, no. July 2021, p. 105870, 2022, doi: 10.1016/j.jaerosci.2021.105870.

[23] Q. Wang *et al.*, "Aerosol transmission of SARS-CoV-2 due to the chimney effect in two high-rise housing drainage stacks," *J. Hazard. Mater.*, vol. 421, no. June 2021, p. 126799, 2022, doi: 10.1016/j.jhazmat.2021.126799.

[24] A. Conway-morris *et al.*, "The removal of airborne SARS-CoV-2 and other microbial bioaerosols by air filtration on COVID-19 surge units," 2021, doi: doi.org/10.1101/2021.09.16.21263684.

[25] W. G. Lindsley *et al.*, "Efficacy of Portable Air Cleaners and Masking for Reducing Indoor Exposure to Simulated Exhaled SARS-CoV-2 Aerosols — United States, 2021," *MMWR. Morb. Mortal. Wkly. Rep.*, vol. 70, no. 27, pp. 972–976, 2021, doi: 10.15585/mmwr.mm7027e1.

[26] J. Villers *et al.*, "SARS-CoV-2 aerosol transmission in schools: the effectiveness of different interventions," *medRxiv*, p. 2021.08.17.21262169, 2021, [Online]. Available: https://www.medrxiv.org/content/10.1101/2021.08.17.21262169v1%0Ahttps://www.medrxiv.org/content/10.1101/2021.08.17.21262169v1.abstract.

[27] Y. Shah, J. W. Kurelek, S. D. Peterson, and S. Yarusevych, "Experimental investigation of indoor aerosol dispersion and accumulation in the context of COVID-19: Effects of masks and ventilation," *Phys. Fluids*, vol. 33, no. 7, 2021, doi: 10.1063/5.0057100.

[28] A. L. Pineda Rojas, S. M. Cordo, R. I. Saurral, J. L. Jimenez, L. C. Marr, and E. Kropff, "Relative Humidity Predicts Day-to-Day Variations in COVID-19 Cases in the City of Buenos Aires," *Environ. Sci. Technol.*, vol. 55, no. 16, pp. 11176–11182, 2021, doi: 10.1021/acs.est.1c02711.

[29] T. P. Smith *et al.*, "Temperature and population density influence SARS-CoV-2 transmission in the absence of nonpharmaceutical interventions," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 118, no. 25, 2021, doi: 10.1073/pnas.2019284118.

[30] R. Pokora *et al.*, "Investigation of superspreading COVID-19 outbreak events in meat and poultry processing plants in Germany: A cross-sectional study," *PLoS One*, vol. 16, no. 6 June, pp. 1–14, 2021, doi: 10.1371/journal.pone.0242456.

[31] Coronavirus (COVID-19) Infection Survey technical article: analysis of reinfections of COVID-19: June 2021 https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/articles/coronaviruscovid19infectionsurveytechnicalarticleanalysisofreinfectionsofcovid19/latest

[32] Coronavirus (COVID-19) Infection Survey, characteristics of people testing positive for COVID-19, UK: 6 October 2021 https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveycharacteristicsofpeopletestingpositiveforcovid19uk/6october2021