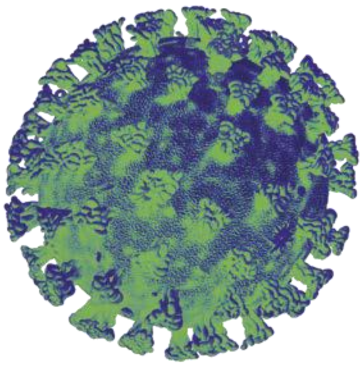
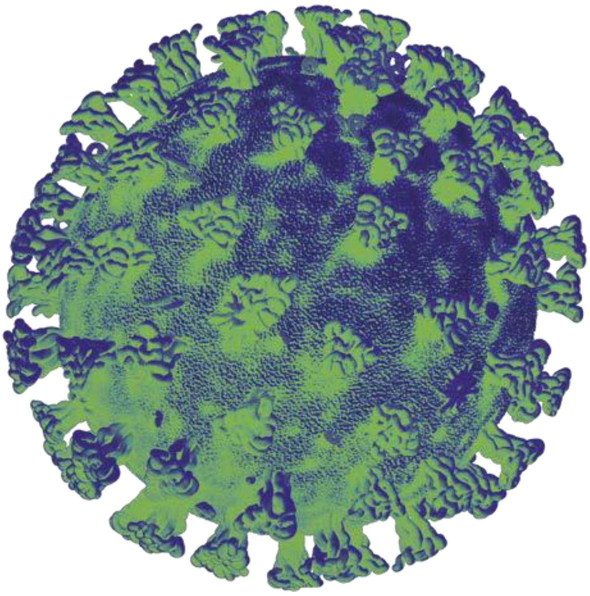
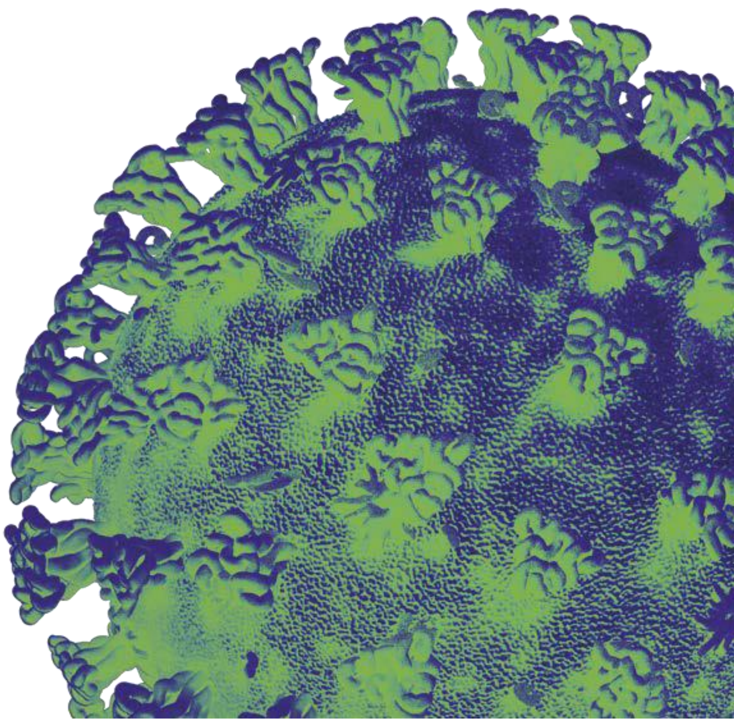
Technical Advisory Group

Consensus Statement on Face Masks for the Public

11 March 2022







Technical Advisory Group

Consensus statement on face masks for the public

11 March 2022

This consensus statement sets out advice on the use of face coverings or masks by the public after the peak of the Omicron wave. We review the latest evidence on their use by the public and provide advice to support any changes to the current mandate of face coverings in Wales. On 14 September 2020 it became mandatory in Wales for face coverings to be worn in most indoor public places. However, under the current mandate there is an exemption for those under the age of 11, and in places where food and drink is served, such as pubs, cafes and restaurants. There are also exemptions for people who cannot wear face coverings for health or medical reasons, similar to those for public transport where it has been mandatory since 27 July 2020. The exemptions are set out in the Face Coverings Guidance for the Public.

The statement considers masks or face coverings (hereafter "masks" unless specified) designed to cover the wearer's mouth and nose which are available to the general public for use within the community. These include cloth face coverings, disposable fluid-resistant surgical masks and higher-grade filtration masks (e.g. FFP2) sold to the general public, but excludes workplace respiratory protective equipment issued as personal protective equipment (PPE). Transparent face shields or visors also fall beyond the scope of this definition. It should be noted that visors or face shields provide limited source control and primarily work as PPE in conjunction with suitable masks rather than as replacements for masks (e.g. Lindsley et al. 2014; Roberge et al. 2014; Akagi et al. 2020).

This consensus statement supersedes the earlier advice, *Statement on face coverings in non-healthcare settings*, published at

Technical Advisory Group: air cleaning devices | GOV.WALES

Table of Contents

1. Executive summary

Face mask use has been widespread across Wales during the pandemic, with most individuals continuing to report face mask use over recent months.

Face masks help mitigate SARS-COV-2 transmission through two different mechanisms: *source control* (preventing onward transmission from an infected wearer) and wearer protection. Widespread use of masks can offer a benefit at the population-level. When worn correctly, masks can reduce transmission through source control at the level of a population if worn by most people.

Mitigations against SARS-CoV-2 transmission must consider all relevant transmission mechanisms and can be combined as *layered protection.* Concomitant use of face masks with other protective measures combines to reduce transmission. With the removal of measures such as distancing, there is still evidence for the benefit of masking to reduce transmission as a supplement to attaining high levels of vaccination.

With the removal of physical distancing measures, enhanced ventilation and face mask use respectively act to mitigate long-range and close-range aerosol transmission. The prominence of face masks is more readily apparent to the public, but this represents the only mitigation which can be implemented with flexibility to reduce close-range transmission.

Inhalation and inspiration of virus particles aerosolised within respiratory secretions represents a prominent mode of transmission. When worn correctly over **mouth and nose**, close-fitting face masks provide wearable filtration to physically impede the transmission of SARS-CoV-2 within these particles. The same principle is relevant for other viruses sharing similar modes of transmission.

The prominence of fine aerosols bearing SARS-CoV-2 from infectious persons poses a challenge for physical filtration. Multiple lines of evidence concur that high-performance face masks (e.g. filtering face-piece (FFP2) respirators) provide greater benefit than other options such as cloth face coverings.

FFP2 respirators (or their N95 equivalent) have been widely used in Europe and the US, with national mandates for their use in public indoor spaces in many European countries, and the provision of free N95 respirators to the public in the US.

Clear standards exist for masks (FFP2/FFP3 respirators: EN 149:2001+A1:2009; community face coverings: BSI 5555; [BSI, 2021]; or in Europe, CWA 17553:2020, [ECDC, 2022]) providing a means of assuring users of their quality.

Transmission can occur in diverse settings, although settings characterised by limited ventilation, high density of occupancy and prolonged or close interactions represent higher risks (high confidence). As a barrier to transmission, face masks are likely to offer most benefit in such settings.

The European Centre for Disease Prevention and Control (ECDC) advises that the use of FFP2 respirators (or type IIR fluid resistant surgical masks) could be considered for cases or for high-risk contacts of individuals with COVID-19 who are unable (or not required) to self-isolate (ECDC, 2022).

A further option is to target the use of face masks in specific settings to help protect people vulnerable to severe COVID-19, such as the elderly and people with underlying medical conditions. In this case, the importance of mask performance and fit is paramount for wearer protection.

The potential environmental impacts of mask use are highly visible through littering and limited opportunities for their recycling. More sustainable ways of using, re-using and disposing of masks are required, with a particular emphasis on effective messaging to the public about sustainable use of masks.

Critically, messaging should also continue to reinforce the rationale behind wearing a mask, the different types available, how they should be worn correctly and the benefits they confer to the wearer and those around them.

The removal of mask legislation may create anxieties for those most vulnerable to COVID-19 as mask use has proven controversial in the UK. Messaging should emphasise that protective measures such as the use of face masks are a positive action which helps protect others and those doing so should be respected.

Contingency plans for e.g. the *COVID Urgent* scenario should include preparations for the use of face masks. This could include logistical preparations, innovation in the development of more sustainable high-performance masks, and messaging about the circumstances and settings in which masks could offer the most benefit.

2. Mask use during the pandemic

Self-reported survey data on the use of face masks during the pandemic has been collected for Wales since March 2020. Reported use grew sharply prior to masks' being required by law, such that by August 2020 around three in five (58%) reported using a mask (Welsh Government, 2022). Since then reported use has been consistently high, such that the most recent data collection (mid-February 2022) suggests around three in four (76%) continue to report wearing a face covering, despite those locations where use is legally required now being limited to retail premises, public transport and healthcare settings. Data from other sources, including the CoMix study (Jarvis et al. 2022), show a similar pattern, although it is clearly important to note the intention-action gap when interpreting self-reported findings such as these. Early evidence from England suggests a fall in the proportions reporting mask use in England following the lifting of protective measures (ONS, 2022) and it will be important to assess this trend in Wales once masks are no longer legally required (Welsh Government, 2022).

3. How face masks work

Proof of the principle that face masks serve as wearable filters to exclude aerosolised pathogens predates the COVID-19 pandemic by 150 years (Tyndall, 1870). The use of face masks as a mitigation in previous respiratory virus pandemics (e.g. Robinson et al. 2021) or to reduce transmission of seasonal respiratory diseases has also been practised continually in countries across the world. Hitherto, there is evidence supporting masking from a randomised controlled trial (Abaluck et al. 2021). The trial was conducted between November 2020 and April 2021 with over 340,000 adults in 600 villages in Bangladesh in which encouragement to use masks increased their use within the population from 13.3% in control villages compared to 42.3% in the intervention villages. This was associated with a reduction in seroprevalence (aOR=0.91, 0.82-1). Their use within a package of non-pharmaceutical interventions in UK countries has proven controversial, with prospect of continued conflict as protections are lifted (SPI-B, 2022). Nonetheless, in a survey of 19,763 adults, 94.5% of those surveyed had worn a face mask between 17 and 27 December 2021 (Abrams et al. 2021-2022). We therefore consider the mechanisms by which face masks may help reduce SARS-CoV-2 transmission.

4. SARS-CoV-2 transmission mitigation through layered protection

SARS-CoV-2 transmission occurs via different pathways, all arising through the emission of infectious particles from the respiratory tract (Milton, 2020; Rutter et al. 2021). A range of different non-pharmaceutical interventions (e.g. physical distancing, hand hygiene, surface cleaning, ventilation enhancement and masking) has been employed as strategies for mitigating SARS-CoV-2 transmission (e.g. Rutter et al. 2021). Although Rutter et al. (2021) note epistemic uncertainties regarding transmission mechanisms and mitigations which are difficult to address via well-designed randomised controlled trials during a pandemic, there is expert consensus that infection following inhalation or inspiration appears more common than contact with contaminated surfaces (Rutter et al. 2021, TAG, 2021). The probability of disease following exposure to coronavirus increases with the dose of coronavirus particles inhaled (SARS: Watanabe et al 2010; SARS-CoV-2: Zhang & Wang, 2021) and therefore mitigations which reduce this inhaled dose reduce the probability of disease transmission. As noted above, other measures include distancing (e.g. Chu et al, 2020) to reduce the exposure to close-range aerosols and droplets (Jones et al. 2020) and ventilation for the dilution of aerosols (SAGE-EMG, 2020). Furthermore, layered protection through the concomitant use of distancing, ventilation and universal masking achieves a synergistic reduction in transmission risk (e.g. Coyle et al. 2022). Therefore, the utility of masking is likely to be enhanced when combined with other measures such as ensuring adequate ventilation (high confidence).

5. The challenge of SARS-CoV-2 in fine aerosols

While individual SARS-CoV-2 virus particles are relatively small (ca. 0.1 µm in diameter; Bar-On, et al. 2020) they are encased within larger particles of respiratory secretions when emitted from infectious individuals. These particles range in size across many orders of magnitude (e.g. viral RNA was found in particles of 0.6 µm to 5 mm in an experimental primate model; Zhang et al. 2021). Infectious SARS-CoV-2 virus has been cultured from aerosols ranging between <1 µm and >5 µm derived from hospitalised COVID-19 patients (Santarpia et al. 2021), mild cases within the community (Lednicky et al. 2021) and confirmed in animal models (Hawks et al. 2021). In all examples cited above, the majority of infectious virus and/or SARS-CoV-2 RNA was contained within <5 µm particles, indicating the importance of reducing the burden of aerosol particle emissions sized between >0.1 µm and <5 µm to decrease the probability of SARS-CoV-2 transmission. Critically, aerosol particles within this size range are produced by normal and symptomatic human behaviour: breathing, speaking, talking, coughing, sneezing (Morawska et al. 2009). The shedding of droplets and aerosols occurs spontaneously during breathing, but the rate and distance of emission is increased by activity and volume of vocalisation (Morawska et al. 2009; Peng et al. 2022).

6. Filtration performance

As described above, in essence, face masks are wearable air filters. The material construction of a face covering influences its ability to filter infectious materials from the airstream around a wearer's mouth and nose. Fischer et al. (2020) found 0.1% of respiratory secretions from a wearer were released through a well-fitted, non-valved N95 (FFP2 equivalent) mask, and low levels of emissions from surgical masks and three-layer face coverings, whereas single-layer bandanas and neck gaiters had little impact on reducing the release of respiratory secretions. Mitigation of transmission risks through physical filtration of infectious aerosols from air is challenging when confronted with small particle sizes, with testing of filter media revealing the most penetrating particle size is typically ca. 0.3 µm (https://www.epa.gov/indoor-air-quality-iaq/what-hepa-filter-1) which is therefore used as the worst-case scenario for testing the efficiency of filters such as high efficiency particulate air (HEPA) used in air cleaning devices or in protective respirators, with FFP2 and FFP3 respirators tested for their ability to block ≥94% and ≥99% of 0.3 µm aerosols respectively (EN149:2001+A1:2009). Smaller particles are harder for cloth masks to trap, demanding better filtration (Asadi et al., 2020; Shakya et al., 2017; Drewnick et al., 2020; Pan et al. 2021) to trap smaller, respirable aerosols (≤5 µm; Milton, 2020). Performance under evaluation greatly differed from manufacturers' claims (Shakya et al., 2017; Asadi et al., 2020). There is evidence the level of virus shedding in exhaled aerosols differs between variants of concern. The peak concentrations of SARS-CoV-2 viral RNA in exhaled breath from double vaccinated cases infected with the Omicron variant of concern is an order of magnitude higher (Zheng et al. 2022) than the highest measured in a study of cases infected with ancestral SARS-CoV-2 measured with the same methodology (Ma et al. 2021), therefore it is possible that different variants of concern differ in their aerosol transmission potential. In a study of SARS-CoV-2 secretion in aerosols from early stage, mild COVID-19 infections, Adenaiye et al. (2021) found cloth and surgical masks reduced SARS-CoV-2 viral RNA emissions within <5 µm aerosols by 48% (95% CI 3-72%) and 77% (95% CI 51-89%) within >5 µm aerosols. Notably Adenaiye et al. (2021) also found a 43-fold (95% CI, 6.6- to 280-fold) increase in viral RNA concentrations within <5 µm aerosols from cases infected with the Alpha (B1.1.7.) variant of concern compared with ancestral SARS-CoV-2. In summary, these observations highlight the importance of high performance filtration for blocking transmission of SARS-CoV-2 present within <5 µm aerosols (high confidence).

7. Fit and adjustment

The efficacy of face masks is also dependent on other considerations such as proper fitting. Human challenge studies with healthy volunteers highlight the importance of shedding from the nose, with high viral loads in the nasal cavity (Killingley et al. 2022) which correlates with detection of infectious virus in face masks, in the air and on surfaces (SAGE 94, 2021). These findings stress the importance of wearing face masks correctly over mouth and nose (high confidence). Konda et al. (2020) reported a 60% decrease in filtration efficiency due to gaps and leakage from poor facial fit. As reported by Drewnick et al. (2020) even small leaks in face masks can reduce their overall effectiveness. The US Centers for Disease Control and Prevention (CDC) (Brooks et al., 2021) conducted a laboratory evaluation of simple mask fit improvements which found single face coverings and surgical masks blocked 54% (±1 SD=7.4%) and 56% (± 1SD=5.8%) of particles from a simulated cough, but the combination of a face covering worn over a surgical mask blocked 85% (± 1SD=2.4%) of emitted particles. This seems likely a function of snug fit as well as additional filtration, given that a knotted-and-tucked surgical mask reduced the release of particles by 77% (± 1SD=3.1). The experiment was modified to consider the additive impact of masks worn by a source and a recipient. When the source and recipient were both fitted with double masks or knotted-and-tucked masks, the cumulative exposure of the recipient was reduced 96.4% (± 1SD=0.02) and 95.9% (± 1SD=0.02), respectively. In response to the Omicron variant, the ECDC (2022) emphasises face masks should completely cover the face from the bridge of the nose down to the chin. The mask should be correctly adjusted on the bridge of the nose and to the face to minimise open space between the face and the mask.

8. The contemporary challenge of source control

The protective impact of face masks used within public spaces and workplaces is the function of two mechanisms; firstly, their ability to offer *source control* by preventing the transmission of virus emitted within the respiratory secretions of a wearer, and secondly a personal protective effect for the wearer (hereafter *wearer protection*). Howard et al. (2021)'s review of mask use identified the strong benefit of face covering use as source control at the population level. The greatest benefits were found when 100% of the population used face masks, with significant impact from (near) universal use at 80% of the population, allowing some headroom for medical exemptions, versus minimal impact where fewer than 50% of the population used face coverings (**Figure 1**).

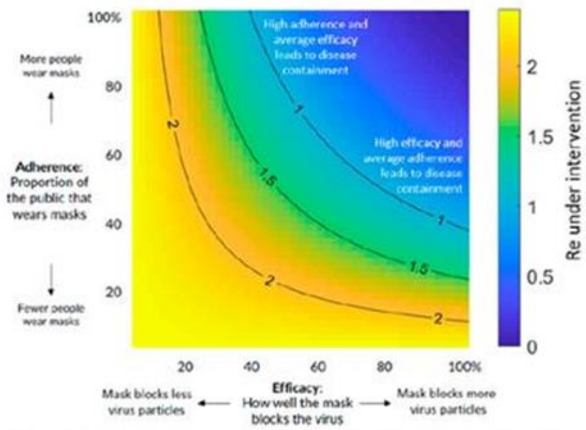


Fig. 1. Impact of public mask wearing under the full range of mask adherence and efficacy scenarios. The color indicates the resulting reproduction number R_e from an initial R_0 of 2.4 (40). Blue area is what is needed to slow the spread of COVID-19. Each black line represents a specific disease transmission level with the effective reproduction number R_e indicated.

Figure 1: The tolerance between adherence and efficacy of face masks. Reproduced from Howard et al. (2021).

When used as part of a layered protection strategy in experimental studies, the universal use of three-layer cloth masks decreased aerosol exposure by 77% (Coyle et al. 2022). However, in isolation, a reduction in population level source control could follow reduced use of face masks in the general population after legal requirements are removed during periods of reduced threat from COVID-19. Targeted use of face masks within specific situations would therefore be required, and the emphasis moves to individual-level source control and wearer protection. These include situations presenting elevated risk or consequence of SARS-CoV-2 transmission.

This could include higher risk settings e.g. enclosed spaces where people from different households congregate at higher density, or occupations resulting in large numbers of close contacts. For example, using a modelling approach considering a train carriage, Miller et al (2022) concluded that strategies to enable high mask-wearing compliance would have notable impact on the dose of virus inhaled by passengers using public transport. The ECDC (2022) advised the use of medical face masks (e.g. a type IIR fluid resistant surgical mask) or respirator (e.g. FFP2/FFP3) for individuals with COVID-19 and others in their household, or for high-risk contacts of individuals with COVID-19 unable (or not required) to self-isolate. Within a higher education institution in the US, exposures where both the infectious person and the contact reported being unmasked were associated with a 40% increase in the odds of a positive COVID-19 test for the contact (Rebmann et al. 2021)

In terms of higher consequence situations, these include individuals with increased likelihood of severe COVID-19 outcomes such as elderly individuals or those with underlying health conditions visiting indoor settings (ECDC, 2022), and in particular settings with a preponderance of individuals at higher risk of severe COVID-19.

Therefore, the importance of ensuring the use of high-performance face masks worn correctly when deployed in specific situations becomes paramount for individual source control and wearer protection, particularly when confronted with a greater level of threat from viruses aerosolised within the <5 µm size fraction as described above (high confidence).

9. Evidence for high performance face masks in community settings

The Scientific Advisory Group for Emergencies' Environmental Modelling Group (SAGE-EMG) concluded that a FFP2 (~N95) type mask offered the best levels of wearer protection and source control relative to other available mask designs (SAGE-EMG, 2021), with evidence that FFP2-equivalent masks provided optimal performance and comfort compared with surgical masks or cloth face coverings (Sharma et al. 2022). Within the US, an observational study of mask effectiveness in preventing COVID-19 transmission in 652 cases and 1,157 controls within indoor public settings between February and December 2021 found consistent use of a cloth mask (aOR = 0.44; 95% CI= 0.17–1.17) was associated with lower adjusted odds of a positive test compared with never wearing a face covering but it was not statistically significant. However, wearing a FFP2-equivalent (N95/KN95) respirator (aOR= 0.17; 95% CI= 0.05–0.64) or wearing a surgical mask (aOR= 0.34; 95% CI = 0.13-–0.90) was associated with lower adjusted odds of a positive test result compared with not wearing a mask (Andrejko et al. 2022). These observations support the US CDC's recommendation of FFP2-equivalent (N95/KN95) masks in community settings updated in January 2022 (https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/types-of-masks.html) and the provision of free FFP2-equivalent (N95/KN95) masks to the general public (https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/free-n95-manufacturers.html). Furthermore, these observations are consistent with experimental studies underpinning policies for widespread FFP2 use in Europe, where FFP2 masks have been required in public indoor settings in many countries (e.g. Germany: https://www.gov.uk/foreign-travel-advice/germany/coronavirus; Italy: https://www.gov.uk/foreign-travel-advice/italy; and Austria: https://www.gov.uk/foreign-travel-advice/austria/coronavirus). Bagheri et al. (2021) compared fluid-resistant surgical masks with FFP2 masks in different experimental scenarios representing either wearer protection, or individual source control or both as mitigation against SARS-CoV-2 transmission during a 20-minute face-to-face conversation (**Figure 2**). Compared with pairwise use of surgical masks, which represented a 10.4% upper-bound risk of infection, the use of FFP2 masks moulded to the noses of both members of the pair reduced the upper-bound risk of infection to 0.14%. It should be noted that the FFP2 masks were not fit-tested or checked as respiratory protective equipment, and the use of FFP2 masks placed on the faces of both parties without adjustment reduced the upper-bound risk of infection to 4.2%. These results suggest that the use of FFP2 masks with simple adjustment to fit considerably reduce the risk of infection from a conversational exposure scenario.

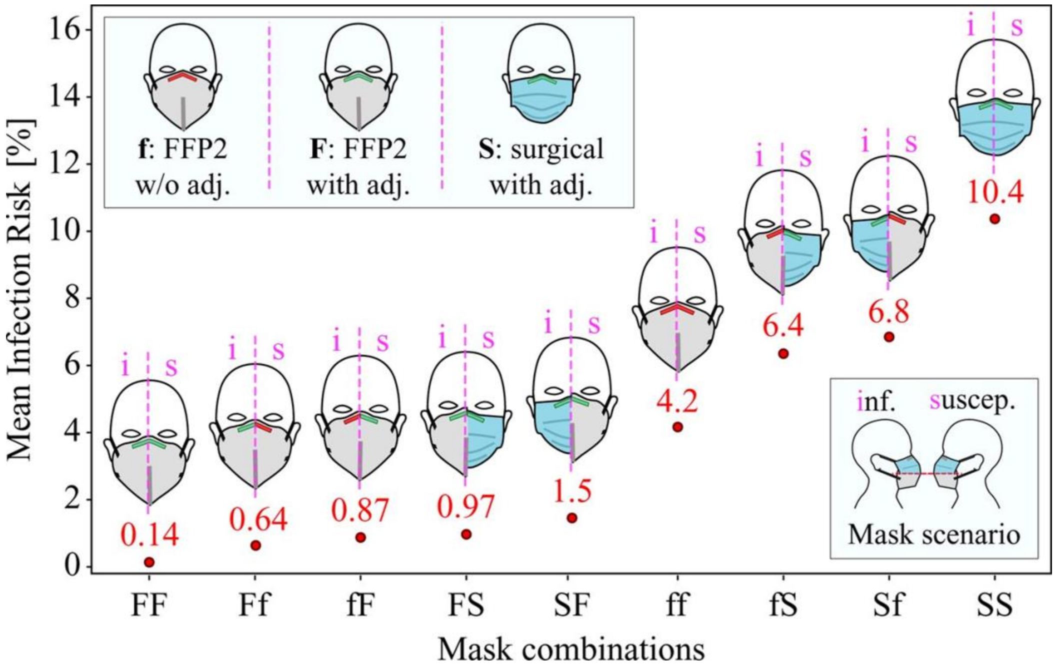


Figure 2: Mean risk of infection in mask scenarios with different mask combinations for a duration of 20 minutes, reproduced from Bagheri et al. (2021). **S** represents a surgical mask with adjustment, **f** represents a FFP2 mask placed directly on the face without adjustment of the fit, and **F** represents a FFP2 mask where the bridge has been adjusted to fit the wearer's face. The combinations represent the pairing of infectious and susceptible wearers.

While many currently wear reusable face masks in most settings, of those that wear disposable masks, 88% wear surgical/IIR masks (unpublished data from Abrams et al. 2021-22). A recommendation for the widespread use of FFP2 masks presents some operational and logistic challenges. These include authenticity and affordability. Around 60% of KN95 (~FFP2) masks tested by US NIOSH in 2020-21 did not meet the required standards (https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/types-of-masks.html). Clear standards exist for masks (FFP2/FFP3 respirators: EN 149:2001+A1:2009; community face coverings: BSI 5555; [BSI, 2021]; or in Europe, CWA 17553:2020, [ECDC, 2022]) providing a means of assuring users.

10. Environmental impacts – disposal, littering, public messaging and reuse

It is hypothesised that more than 3.3 billion disposable face masks will be discarded everyday around the world, if and when the facemask/covering acceptance rate reaches 70-80% (Benson, 2021). In certain countries (mainly Asian) this may not represent a huge spike on the facemask/covering usage as these countries have already adopted facemask/covering usage as a part of their daily life. However, this new adopted daily routine could create new and unfamiliar waste management issues for the other countries including Wales. Currently, only 1 to 5% of masks are being recycled (unpublished data from Abrams et al. 2021-2022) and there is limited capacity for mask or non-woven polypropylene recycling by the polymer industry.

One of the main issues with handling disposable face mask waste is that the main material used in production of these disposable face masks is polypropylene (PP) and unlike other plastics such as HDPE and PETE, PP is not widely recycled (Kleme et al., 2020). Therefore, a dynamic management approach to this new type of solid waste needs to be developed and regulated. The waste management options for disposable face masks which need to be considered for their environmental and economic impacts are summarised in **Figure 3**.

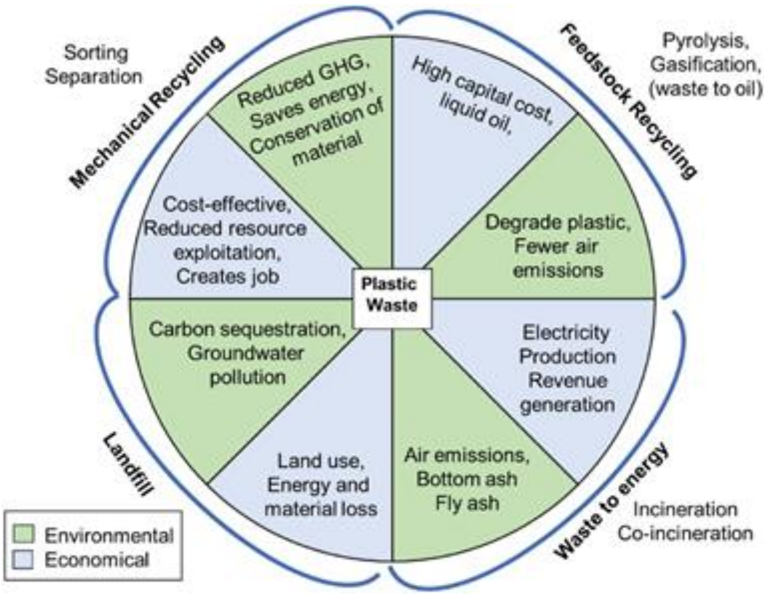


Figure 3. Environmental and economic performance of various plastic waste management approaches (Vanapali et al., 2019).

Another issue with the increased usage of disposable face masks is their improper disposal and their impact on our immediate environment, including water sources. A high degree of mask littering has been observed in urban and recreational spaces, indicating poor disposal into available waste handling facilities. If such plastics enter watercourses and ultimately the sea, they contribute to marine plastic, and can be associated with adsorption of heavy metals or persistent organic pollutants (Selvaranjan et al. 2021). Recent publications showed that a considerable portion of these disposable face masks have been disposed of improperly and end up in waterways and/or in bulk water sources (lakes, oceans, etc.; Benson, 2021; Prata et al., 2020). A recent paper from Wales showed that all the tested disposable face masks (300+ from nine separate brands) leached or shed micro- and nanosized plastics and silicon-based particles to water when submerged and agitated gently to simulate improper disposal to water sources (Sullivan et al., 2021). The same work showed that, in addition to plastic and silicon-based particles, a majority of these disposable face masks leach heavy metals and non-volatile organics to the water as well, including dyes and plasticisers.

Both issues outlined above can be addressed and/or optimised in the longer term by policy options which could include enforcing the use of high-quality and recyclable materials in the manufacturing of disposable face masks. In the shorter term, guidance for appropriate disposal and appropriate reuse of disposable face masks can reduce the environmental impacts. Media messages should clearly convey that a) reusable masks are available that are just as safe and comfortable as disposable ones (Eikenberry et al. 2020), and b) that disposable masks should be disposed of conscientiously with consideration be given to more sustainable alternatives. Terminology may need to be revised and clarified for more consistent use. This also includes the widespread use of the mask required pictogram that, invariably, depicts a single-use mask.

Media representations mostly ignore the environmental impact of disposable masks. Most references are simply to 'masks' which are associated with disposable masks, thus subtly suggesting this as the preferred (or only available) choice. People are therefore not guided in their choice and may believe it does not matter – or that disposable masks are safer. This may be related to pre-pandemic messages which identified reusable face-coverings as non-medical items, whereas disposable masks have traditionally been associated with safety measures in the media. The official messaging, which is pro-disposable masks as almost mandatory, is undermined by other media that are more immersive (social media, film, music videos, etc.). Such media reflect much more critical and diverse perspectives on mask-wearing, including the use of more sustainable options (cloth face coverings). Hence, the promotion of sustainable mask-wearing practices through other media could be considered.

Existing descriptions of the environmental impact of disposable masks insist on the uncertainty about the possibility to recycle the masks, but they downplay the threat represented by the environmental impact.

Reusable face coverings play a significant role in people's actual behaviour, creating a mismatch with media messaging (which focuses heavily on disposable masks) and associated assumptions as to efficacy and sustainability concerns. Many people firmly (and correctly) believe that disposable face coverings are safer, or they complain that the media should do more to point to the environmental impact of disposable masks. Reusable face coverings therefore need to be taken more seriously as an advantageous environmental choice. Of 19,763 adults surveyed, 94.5% had worn a face covering between 17 and 27 December 2021 (Abrams et al. 2021-2022). Most of those surveyed wear reusable face coverings rather than disposable face masks in most settings, but more people tend to wear disposable face coverings in health and medical centres.

As detailed above, more people wear the surgical/IIR type disposable masks than the more effective FFP2/3 respirators, despite ranking efficacy as a key factor when choosing what type of mask to wear. Those who chose not to wear masks do so because they do not believe they are effective. People seem more likely to adhere to non-pharmaceutical interventions if they are considered effective.

However, the choice of face mask varies in different locations. In large indoor public spaces, marginally more people wore reusable face coverings (50.1%) than disposable face coverings (41.9%), and those who wore disposable face coverings mainly wore surgical/IIR masks (88.2%). Similar patterns occur in small indoor public spaces; while outdoors; when visiting friends and family from other households and when visiting hospitality settings. Contrary to the other settings, more people (55.5%) wore disposable than reusable (38.4%) face coverings when visiting medical centres. The level of crowding (57.3%), familiarity with people (53.2%) and being around those who are more at risk from COVID-19 (54.1%) were reported as having the most influence on face covering choices, i.e., the decision to wear or not to wear a face covering (all data from an unpublished survey of 19,763 adults; Abrams et al. 2021-2022).

Masks are unlikely to be recycled and some are discarded as litter, highlighting a serious sustainability and environmental issue when the scale of mask-wearing is considered. Greenhouse gas emissions (carbon footprint) can vary a considerable amount dependent on the type of face mask (constituent ingredients and manufacturing process), the frequency of use or washing, and the end-of-life disposal (Abrams et al. 2021-2022). A significant benefit is seen for reusable cloth face coverings, even when washed frequently at 60 °C and disposed of after just 20 uses (the strict behaviour scenario, reflecting NHS guidelines and manufacturer instructions). When wash temperature and frequency were adjusted, further reductions in CO_2 emissions were observed.

Although respirators (e.g. FFP2/FFP3) are typically marked as non-reusable, the COVID-19 pandemic has stimulated a range of efforts to establish means of their re-use. A key challenge is the potential risk of infection from reuse of contaminated masks; masks worn by COVID-19 cases become contaminated (Williams et al. 2021) and therefore masks should not be shared between users. ECDC (2020) set out options for decontamination and reuse of face masks in health care settings. Most of the options identified required technical interventions, however storage and re-use of masks on five- to seven-day day cycles is more feasible (e.g.: https://www.fh-muenster.de/gesundheit/forschung/forschungsprojekte/moeglichkeiten-und-grenzen-der-eigenverantwortlichen-wiederverwendung-von-ffp2-masken-im-privatgebrauch/index.php). Damaged masks, visibly soiled masks, or masks used in settings with a high probability of contamination should not be reused.

11. Face masks and equity

Previous advice has emphasised the importance of support to encourage adherence to protective measures and address inequality, including financial support (see for example SPI-B, 2021; TAG, 2021). This is particularly important regarding mask use if more effective masks are being recommended to enhance protection, given current cost considerations. Thought will need to be given to how such masks can be made available, or more affordable, for those least able to pay for them in order not to further exacerbate those inequities that have become apparent during the pandemic. A recent US-based modelling study examined the costs of mask use in relation to their benefit in mitigating transmission in conjunction with increasing vaccination coverage (Bartsch et al. 2022). The study determined that the widespread use of masks could not only be cost-effective, but even cost-saving across a range of scenarios during and shortly after the attainment of vaccination targets to the extent that subsidy of mask purchase costs could be a viable strategy. The authors considered the cost-benefit of masks would be more favourable in the face of more transmissible variants.

12. Face masks and the emergence of a future variant

SAGE (2022) has identified scenarios in which the emergence of novel variants of concern in the mid-term future could undermine the control of COVID-19. For its “central optimistic” scenario, the reintroduction of face masks in some countries is identified as a potential mitigation. Provided a novel variant of concern shares similar transmission mechanisms with extant variants of SARS-CoV-2, face masks can be deployed at scale and at short notice to mitigate against the transmission of a novel variant of concern. This is of particular value where medical countermeasures (e.g. vaccines, antivirals) may be variable in their efficacy in the event of an immune-evasive or antiviral-resistant variant, and have longer lead times for deployment at scale. It is therefore important to prepare for the early deployment of face masks in such an eventuality. Such preparations could take the form of building manufacturing capacity, development of masks with reduced environmental impact, and ensuring contingency stockpiles. Messaging to the public should emphasise the kind of scenarios in which face masks could be required in different settings and normalise their use (e.g. Welsh Government, 2022; Scottish Government, 2022). Messaging should also continue to reinforce the rationale behind wearing a mask, the different types available, how they should be worn correctly and the benefits they confer to the wearer and those around them.

13. Areas for further development

This section considers some uncertainties and directions for development. The COVID-19 pandemic has been described as the “perfect epistemic storm” (Levy & Savulescu, 2020) and as described above, epistemic uncertainties impinge upon our understanding of SARS-CoV-2 transmission mechanisms and mitigations (Rutter et al. 2021). This includes the use of masks within the community. During the course of a fast-moving pandemic, managing high-quality randomised controlled trials to test the efficacy of face masks has proven challenging but not impossible (e.g. Abaluck et al. 2021). This is complicated by confounding factors such as variations in mask design, behaviour and usage, and the role of masks within a package of multiple interventions. While this paper summarises a range of experimental, mechanistic and observational evidence supporting the use of masks as mitigation, emerging opportunities to conduct robust trials on the effectiveness and utility of masks in different community settings could be exploited to complement the existing evidence-base. A key success in the response to the pandemic was the prompt establishment of randomised controlled trials for pharmaceutical interventions (e.g. Wilkinson, 2020). Preparations for resurgences in COVID-19 or the emergence of new pandemics could include prior planning for assembling high-quality evidence on proposed non-pharmaceutical interventions at pace.

There is limited evidence for the disbenefits of widespread mask use (Bakhit et al. 2021), and their adverse impacts may be less severe than other non-pharmaceutical interventions. However, an important consideration is that face masks can limit communication, for example for people who are D/deaf. While a range of transparent face masks exists, evidence for their effectiveness is limited or varied. The department for Health and Social Care (DHSC) recently set out a technical specification for a transparent face mask equivalent to a type II/R fluid-resistant surgical mask but concluded that there was no evidence of equivalent performance between any transparent mask and a type II/R mask available at the time of writing (https://www.gov.uk/government/publications/technical-specifications-for-personal-protective-equipment-ppe/transparent-face-mask-technical-specification). This led to their recommendation for further research and development in this area.

Finally, as set out in this paper, there are many designs of face mask which differ in their effectiveness, comfort, sustainability, accessibility and cost. Any single design represents a compromise between competing priorities. Research and development for an optimal face mask design faces a challenging set of design criteria. These would include: high performance (FFP2 or better), snug fit for a range of face shapes, low breathing resistance, high comfort, transparent and fog-resistant for communication, and deployable quickly and at scale, yet at low economic and environmental cost (e.g. biodegradable, recyclable, reusable).

References

Abaluck, J., Kwong, L.H., Styczynski, A., Haque, A., Kabir, M.A., Bates-Jefferys, E., Crawford, E., Benjamin-Chung, J., Raihan, S., Rahman, S. and Benhachmi, S., 2021. Impact of community masking on COVID-19: A cluster-randomized trial in Bangladesh. *Science*, p.eabi9069.

Abrams, N., Augé, A, Hassan, L., A., Nowakowski, M., Roberts, G., Roberts, H., Spear, M., Steele, S., Tenbrink, T., Hassan, L. Willcock, S. 2021-2022. Between environmental concerns and compliance: How does media messaging affect motivation and choice between disposable versus reusable facemasks? AHRC grant no. AH/W003813/1.

Adenaiye, O.O., Lai, J., de Mesquita, P.J.B., Hong, F.H., Youssefi, S., German, J.R., Tai, S.H.S., Albert, B.J., Schanz, M., Weston, S. and Hang, J., 2021. Infectious SARS-CoV-2 in exhaled aerosols and efficacy of masks during early mild infection. Preprint; DOI: https://doi.org/10.1093/cid/ciab797.

Akagi, F., Haraga, I., Inage, S.I. and Akiyoshi, K., 2020. Effect of sneezing on the flow around a face shield. *Physics of Fluids*, 32(12), p.127105.

Andrejko, K.L., Pry, J.M., Myers, J.F., Fukui, N., DeGuzman, J.L., Openshaw, J., Watt, J.P., Lewnard, J.A., Jain, S., COVID, C. and COVID, C., 2022. Effectiveness of Face Mask or Respirator Use in Indoor Public Settings for Prevention of SARS-CoV-2 Infection—California, February–December 2021. *Morbidity and Mortality Weekly Report,* 71(6), p.212.

Asadi, S., Cappa, C.D., Barreda, S., Wexler, A.S., Bouvier, N.M. and Ristenpart, W.D., 2020. Efficacy of masks and face coverings in controlling outward aerosol particle emission from expiratory activities. *Scientific Reports*, 10(1), pp.1-13.

Bagheri, G., Thiede, B., Hejazi, B., Schlenczek, O. and Bodenschatz, E., 2021. An upper bound on one-to-one exposure to infectious human respiratory particles. *Proceedings of the National Academy of Sciences*, 118(49).

Bakhit, M., Krzyzaniak, N., Scott, A.M., Clark, J., Glasziou, P. and Del Mar, C., 2021. Downsides of face masks and possible mitigation strategies: a systematic review and meta-analysis. *BMJ Open*, 11(2), p.e044364.

Bar-On, Y.M., Flamholz, A., Phillips, R. and Milo, R., 2020. Science Forum: SARS-CoV-2 (COVID-19) by the numbers. *elife*, 9, p.e57309.

Bartsch, S.M., O'Shea, K.J., Chin, K.L., Strych, U., Ferguson, M.C., Bottazzi, M.E., Wedlock, P.T., Cox, S.N., Siegmund, S.S., Hotez, P.J., Lee, B.Y., 2022. Maintaining face mask use before and after achieving different COVID-19 vaccination coverage levels: a modelling study. *Lancet Public Health*. DOI: 10.1016/S2468-2667(22)00040-8 [Epub ahead of print]

Benson, N. U. (2021). COVID pollution: Impact of COVID-19 pandemic on global plastic waste footprint. *Heliyon*, 7, e06343.

British Standards Institute (BSI), 2021. *Community Face Coverings - Specification*. BSI Flex 5555 v 2.

Brooks, J.T., Beezhold, D.H., Noti, J.D., et al. 2021. Maximizing fit for cloth and medical procedure masks to improve performance and reduce SARS-CoV-2 transmission and exposure, 2021. *Morbidity and Mortality Weekly Report* 70:254–257. DOI: 10.15585/mmwr.mm7007e1

Chu, D.K., Akl, E.A., Duda, S., Solo, K., Yaacoub, S., Schünemann, H.J., El-harakeh, A., Bognanni, A., Lotfi, T., Loeb, M. and Hajizadeh, A., 2020. 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. *Lancet*, 395(10242), pp.1973-1987.

Coyle, JP, Derk, RC, Lindsley, WG, et al. Reduction of exposure to simulated respiratory aerosols using ventilation, physical distancing, and universal masking. *Indoor Air.* 2022; 32:e12987. DOI: https://doi.org/10.1111/ina.12987

Drewnick, F., Pikmann, J., Fachinger, F., Moormann, L., Sprang, F. and Borrmann, S., 2021. Aerosol filtration efficiency of household materials for homemade face masks: Influence of material properties, particle size, particle electrical charge, face velocity, and leaks. *Aerosol Science and Technology*, 55(1), pp.63-79.

ECDC. (European Centre for Disease Prevention and Control) 2020. *Options for the Decontamination and Reuse of Respirators in the Context of the COVID-19 Pandemic*. 8 June 2022.

https://www.ecdc.europa.eu/sites/default/files/documents/Options-for-shortage-of-surgical-masks-and-respirators.pdf

ECDC. 2022). *Considerations for the Use of Face Masks in the Community in the Context of the SARS-CoV-2 Omicron Variant of Concern*, 7 February 2022. https://www.ecdc.europa.eu/sites/default/files/documents/Considerations-for-use-of-face-masks-in-the-community-in-the-context-of-the-SARS-CoV-2-Omicron-variant-of-concern.pdf

Eikenberry, S.E., Mancuso, M., Iboi, E., Phan, T., Eikenberry, K., Kuang, Y., Kostelich, E. and Gumel, A.B., 2020. To mask or not to mask: Modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic. *Infectious Disease Modelling*, 5, pp.293-308.

Fischer, E.P., Fischer, M.C., Grass, D., Henrion, I., Warren, W.S. and Westman, E., 2020. Low-cost measurement of face mask efficacy for filtering expelled droplets during speech. *Science Advances*, 6(36), p.eabd3083.

Hawks, S.A., Prussin, A.J., Kuchinsky, S.C., Pan, J., Marr, L.C. and Duggal, N.K., 2021. Infectious SARS-CoV-2 is emitted in aerosol particles. *mBio*, 12(5), pp.e02527-21.

Howard, J., Huang, A., Li, Z., Tufekci, Z., Zdimal, V., van der Westhuizen, H.M., von Delft, A., Price, A., Fridman, L., Tang, L.H. and Tang, V., 2021. An evidence review of face masks against COVID-19. *Proceedings of the National Academy of Sciences*, 118(4).

Jones, N.R., Qureshi, Z.U., Temple, R.J., Larwood, J.P., Greenhalgh, T. and Bourouiba, L., 2020. Two metres or one: what is the evidence for physical distancing in covid-19?. *BMJ*, 370.

Killingley, B., Mann, A., Kalinova, M., Boyers, A., Goonawardane, N., Zhou, J., Lindsell, K., Hare, S.S., Brown, J., Frise, R. and Smith, E., 2022. Safety, tolerability and viral kinetics during SARS-CoV-2 human challenge. Preprint; DOI: 10.21203/rs.3.rs-1121993/v1

Konda, A., Prakash, A., Moss, G.A., Schmoldt, M., Grant, G.D. and Guha, S., 2020. Aerosol filtration efficiency of common fabrics used in respiratory cloth masks. *ACS Nano,* 14(5), pp.6339-6347.

Lednicky, J.A., Lauzardo, M., Alam, M.M., Elbadry, M.A., Stephenson, C.J., Gibson, J.C. and Morris Jr, J.G., 2021. Isolation of SARS-CoV-2 from the air in a car driven by a COVID patient with mild illness. *International Journal of Infectious Diseases*, 108, pp.212-216.

Levy, N. and Savulescu, J., 2020. Epistemic responsibility in the face of a pandemic. *Journal of Law and the Biosciences*, 7(1), p.lsaa033.

Lindsley, W.G., Noti, J.D., Blachere, F.M., Szalajda, J.V. and Beezhold, D.H., 2014. Efficacy of face shields against cough aerosol droplets from a cough simulator. *Journal of Occupational and Environmental Hygiene,* 11(8), pp.509-518

Ma, J., Qi, X., Chen, H., Li, X., Zhang, Z., Wang, H., Sun, L., Zhang, L., Guo, J., Morawska, L. and Grinshpun, S.A., 2021. Coronavirus disease 2019 patients in earlier stages exhaled millions of severe acute respiratory syndrome coronavirus 2 per hour. *Clinical Infectious Diseases*, 72(10), pp.e652-e654.

Miller, D., King, M.F., Nally, J., Drodge, J.R., Reeves, G.I., Bate, A.M., Cooper, H., Dalrymple, U., Hall, I., López-García, M. and Parker, S.T., 2022. Modeling the factors that influence exposure to SARS-CoV-2 on a subway train carriage. *Indoor Air*, p.e12976.

Milton, D.K., 2020. A Rosetta Stone for understanding infectious drops and aerosols. *Journal of the Pediatric Infectious Diseases Society*, 9(4), pp.413-415.

Morawska, L.J.G.R., Johnson, G.R., Ristovski, Z.D., Hargreaves, M., Mengersen, K., Corbett, S., Chao, C.Y.H., Li, Y. and Katoshevski, D., 2009. Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities. *Journal of Aerosol Science*, 40(3), pp.256-269.

Pan, J., Harb, C., Leng, W. and Marr, L.C., 2021. Inward and outward effectiveness of cloth masks, a surgical mask, and a face shield. *Aerosol Science and Technology*, 55(6), pp.718-733.

Peng, Z., Rojas, A.P., Kropff, E., Bahnfleth, W., Buonanno, G., Dancer, S.J., Kurnitski, J., Li, Y., Loomans, M.G., Marr, L.C. and Morawska, L., 2022. Practical indicators for risk of airborne transmission in shared indoor environments and their application to covid-19 outbreaks. *Environmental Science and Technology*. 56, 2, 1125–1137

Prata, J. C., Silva, A. L. P., Walker, T. R., Duarte, A. C., & Rocha-Santos, T., 2020. COVID-19 pandemic repercussions on the use and management of plastics. *Environmental Science and Technology*, 54(13), 7760–7765.

Rebmann, T., Loux, T.M., Arnold, L.D., Charney, R., Horton, D. and Gomel, A., 2021. SARS-CoV-2 Transmission to masked and unmasked close contacts of university students with COVID-19—St. Louis, Missouri, January–May 2021. *Morbidity and Mortality Weekly Report*, 70(36), p.1245.

Roberge, R.J., 2016. Face shields for infection control: A review. *Journal of Occupational and Environmental Hygiene*, 13(4), pp.235-242.

Robinson, K.R., 2021, April. Comparing the Spanish flu and COVID-19 pandemics: Lessons to carry forward. *Nursing Forum* (Vol. 56, No. 2, pp. 350-357).

Rutter, H., Parker, S., Stahl-Timmins, W., Noakes, C., Smyth, A., Macbeth, R., Fitzgerald, S. and Freeman, A.L., 2021. Visualising SARS-CoV-2 transmission routes and mitigations. *BMJ*, 375.

SAGE (Scientific Advisory Group for Emergencies) *94*, 2021. 22 July 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1052577/S1345_SAGE_94_Minutes__1_.pdf

SAGE, 2022. *Academics: viral evolution scenarios*, 10 February 2022 https://www.gov.uk/government/publications/academics-viral-evolution-scenarios-10-february-2022

SAGE-EMG (Environmental Modelling Group), 2020. *Role of ventilation in controlling COVID-19 transmission.* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928720/S0789_EMG_Role_of_Ventilation_in_Controlling_SARS-CoV-2_Transmission.pdf

SAGE-EMG., 2021. *Annex 1 - EMG Consensus statement on face coverings*, 28 September 2021 https://www.gov.uk/government/publications/spi-b-spi-m-and-emg-considerations-for-potential-impact-of-plan-b-measures-13-october-2021

Santarpia, J.L., Herrera, V.L., Rivera, D.N., Ratnesar-Shumate, S., Reid, S.P., Ackerman, D.N., Denton, P.W., Martens, J.W., Fang, Y., Conoan, N. and Callahan, M.V., 2021. The size and culturability of patient-generated SARS-CoV-2 aerosol. *Journal of Exposure Science and Environmental Epidemiology*, pp.1-6. DOI: The size and culturability of patient-generated SARS-CoV-2 aerosol | Journal of Exposure Science & Environmental Epidemiology (nature.com)

Scottish Government, 2022. *COVID-19 Scotland's Strategic Framework Update*, 22 February 2022 https://www.gov.scot/publications/coronavirus-covid-19-scotlands-strategic-framework-update-february-2022/documents/

Selvaranjan, K., Navaratnam, S., Rajeev, P. and Ravintherakumaran, N., 2021. Environmental challenges induced by extensive use of face masks during COVID-19: A review and potential solutions. *Environmental Challenges*, 3, p.100039.

Shakya, K.M., Noyes, A., Kallin, R. and Peltier, R.E., 2017. Evaluating the efficacy of cloth facemasks in reducing particulate matter exposure. *Journal of Exposure Science and Environmental Epidemiology,* 27(3), pp.352-357.

Sharma, A., Omidvarborna, H. and Kumar, P., 2022. Efficacy of facemasks in mitigating respiratory exposure to submicron aerosols. *Journal of Hazardous Materials,* 422, p.126783.

SPI-B (SAGE Scientific Pandemic Insights Group on Behaviours), 2022. *Social and behavioural impacts for lifting remaining restrictions*, 10 February 2022 https://www.gov.uk/government/publications/spi-b-social-and-behavioural-impacts-for-lifting-remaining-restrictions-10-february-2022/spi-b-social-and-behavioural-impacts-for-lifting-remaining-restrictions-10-february-2022--2

Sullivan, G. L., Delgado-Gallardo, J., Watson, T. M., & Sarp, S., 2021. An investigation into the leaching of micro and nano particles and chemical pollutants from disposal face masks—linked to the COVID-19 pandemic. *Water Research*, 117033. https://doi.org/10.1016/j.watres.2021.117033

TAG, 2021. Technical Advisory Group: evidence review of ozone generators including appropriateness as mitigation in classrooms https://gov.wales/technical-advisory-group-evidence-review-ozone-generators-including-appropriateness-mitigation

Tyndall. J., 1870. On Haze and Dust. *Nature* 1, 339–342

Watanabe, T., Bartrand, T.A., Weir, M.H., Omura, T. and Haas, C.N., 2010. Development of a dose-response model for SARS coronavirus. *Risk Analysis: an International* Journal, 30(7), pp.1129-1138.

Welsh Government, 2022. *Together for a safer future: Wales' long-term Covid-19 transition from pandemic to endemic*. https://gov.wales/sites/default/files/publications/2022-03/wales-long-term-covid-19-transition-from-pandemic-to-endemic.pdf

Wilkinson, E., 2020. RECOVERY trial: the UK COVID-19 study resetting expectations for clinical trials. *BMJ*, 369.

Williams, C.M., Pan, D., Decker, J., Wisniewska, A., Fletcher, E., Sze, S., Assadi, S., Haigh, R., Abdulwhhab, M., Bird, P. and Holmes, C.W., 2021. Exhaled SARS-CoV-2 quantified by face-mask sampling in hospitalised patients with COVID-19. *Journal of Infection*, 82(6), pp.253-259.

Zhang, C., Guo, Z., Zhao, Z., Wang, T., Li, L., Miao, F., Zhang, C., Li, Y. and Gao, Y., 2021. SARS-CoV-2 aerosol exhaled by experimentally infected cynomolgus monkeys. *Emerging Infectious Diseases*, 27(7), p.1979.

Zhang, X. and Wang, J., 2021. Dose-response relation deduced for coronaviruses from coronavirus disease 2019, severe acute respiratory syndrome, and middle east respiratory syndrome: Meta-analysis results and its application for infection risk assessment of aerosol transmission. *Clinical Infectious Diseases*, 73(1), pp.e241-e245.

Zheng, J., Wang, Z., Li, J., Zhang, Y., Jiang, L., Fu, Y., Jin, Y., Cheng, H., Li, J., Chen, Z. and Tang, F., 2022. High amounts of SARS-CoV-2 in aerosols exhaled by patients with Omicron variant infection. *Journal of Infection*. DOI: https://doi.org/10.1016/j.jinf.2022.02.015