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PERSPECTIVE

Revisiting the rationale of mandatory masking

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Abstract

In this perspective, we review the evidence for the efficacy of face masks to reduce the transmission of respiratory viruses, specifically severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and consider the value of mandating universal mask wearing against the widespread negative impacts that have been associated with such measures. Before the SARS-CoV-2 pandemic, it was considered that there was little to no benefit in healthy people wearing masks as prophylaxis against becoming infected or as unwitting vectors of viral transmission. This accepted policy was hastily reversed early on in the pandemic, when districts and countries throughout the world imposed stringent masking mandates. Now, more than three years since the start of the pandemic, the amassed studies that have investigated the use of masks to reduce transmission of SARS-CoV-2 (or other pathogens) have led to conclusions that are largely inconsistent and contradictory. There is no statistically significant or unambiguous scientific evidence to justify mandatory masking for general, healthy populations with the intention of lessening the viral spread. Even if mask wearing could potentially reduce the transmission of SARS-CoV-2 in individual cases, this needs to be balanced against the physical, psychological and social harms associated with forced mask wearing, not to mention the negative impact of innumerable disposed masks entering our fragile environment. Given the lack of unequivocal scientific proof that masks have any effect on reducing transmission, together with the evident harms to people and the environment through the use of masks, it is our opinion that the mandatory use of face masks in the general population is unjustifiable and must be abandoned in future pandemic countermeasures policies.

1. Preamble

In early 2020, world media outlets reported the emergence of a hitherto unknown virus, named severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2, in the city of Wuhan in the Hubei province of China, a purportedly highly infectious agent inducing respiratory disruption and, ultimately, death across the adult population. Reports soon arose of patients elsewhere presenting similar symptoms to those encountered in Wuhan, first in other countries on the Asian continent, then in Europe and North America, signifying its unmitigated spread. These events marked the start of the global coronavirus disease 2019, or COVID-19, pandemic and the contemporaneous complete and lasting disruption to the freedoms and daily routines in modern day societies as governments collectively and almost simultaneously introduced and imposed restrictive measures on populations in reaction to this outbreak. Countermeasures included recommendations or mandates on regular hand disinfection, social distancing, travel restrictions, curbed access to public facilities, national lockdowns, and the mandatory wearing of facial coverings. Once reserved to the hospital operating theatre with the intention to prevent wound infection in patients [1] and to protect medical staff from oral exposure to blood or bodily fluid splashes—a practice that in itself has been thrown into doubt [2, 3]—the past three years have seen face masks becoming commonplace in towns and cities throughout the world as citizens navigate through their daily lives with the omnipresent threat of an invisible foe.

As the transformative events of early 2020 played out, with the World Health Organization (WHO) elevating the status of SARS-CoV-2 from endemic to epidemic, and then to pandemic, the medical and scientific communities throughout the world undertook efforts towards lessening its impact. These endeavours included developing and trialing therapeutic treatments, examining and characterizing the nature of the disease, and exploring measures to curb viral spread. The unprecedented situation called for quick action, but was accompanied by countless unknowns. Thus, many efforts and initiatives were in uncharted territory, thereby elevating the likelihood of flaws and failures.

Although the evidence for the veracity of mask wearing was sparse at the beginning of the pandemic, the approach adopted in many countries around the world of encouraging or mandating healthy populations to wear face masks when interacting with other people appeared to be a sensible one. Surely the introduction of a physical obstruction directly at the potential source of viral dispersal, i.e. between an unwitting host and the host's immediate surroundings, should lessen the spread of virions into the environment? Evidence for the retention of small endogenous molecules (in the form of cytokines) in the fabric of used hospital masks, for example, indicate that organic materials embedded in exhaled aerosol are indeed retained, to some degree, when breath passes through such a permeable barrier [4]. An editorial published in this journal—and co-authored by one of the present authors—at the outset of these unprecedented circumstances, motivated by a desire to contribute to lessening the reach of the pandemic, presented the latter case as one rationale for the use of masks to reduce community exposure to the virus [5]. With the benefit of hindsight, however, and supported by the body of scientific work that has emerged over the past three years, the recommended or mandated use of face masks to stem the pandemic—ethical issues aside [6]—is one swiftly and widely imposed measure that, as outlined on the basis of evidence presented herein, has not only failed to hinder the spread of infection, but has caused previously unforeseen widespread negative impacts to society and the environment.

This perspective piece explores the efficacy of commonly-worn face masks (e.g. cloth masks, surgical masks and N95/FFP2-type[4] masks) in reducing the spread of SARS-CoV-2 and presents a casebook of the 'collateral damage' of encouraged or enforced mask-wearing, with evidence from latest research spanning the fields of epidemiology, physiology, virology and psychology, to environmental science. Taking a critical stance on any COVID-19 pandemic countermeasures is demonstrably a precarious pursuit [7, 8], but the intention of this article is to consider the arguments for and against mask-wearing and mask mandates based on the latest findings and the current state of knowledge in a rational and factual manner, as is necessary for healthy scientific discourse and debate. By definition, the discipline of science must be objective, with theories being developed based on the available evidence in favour of a particular hypothesis. In many cases, however, independent research might produce an outcome that conflicts with and thereby throws into question the contemporarily accepted theory. Consequently, ideas and concepts can evolve as the dossier of research overwhelmingly supports or contradicts a particular position, leading to a scientific consensus. In the present article, the theory that face masks of the type that have been commonly mandated and worn during the COVID-19 pandemic play a significant role in stemming viral transmission is questioned and discussed based on the current, relevant scientific literature. This article is written as a perspective, which caters for a 'personal view on a particular research topic or discipline'. In composing this article, the collective body of literature, as cited herein, is interpreted and discussed to form a viewpoint. The overwhelming evidence leads the authors to conclude that mandating masks in general populations is ineffective and obsolete, as is outlined in the ensuing text. The article commences by revisiting the early rationale for mask use.

2. Efficacy of face masks in reducing transmission

Before the SARS-CoV-2 pandemic, the general consensus amongst public health organizations and officials was that it was not necessary to mask healthy people in community settings to reduce the transmission of viral infections. This position was modified at the start of the pandemic to advise mask-wearing only to people with symptoms of viral infection or to medical workers or carers interacting with symptomatic people in home and healthcare settings; medical face masks were deemed not required within a

[4] N95 and FFP2 (filtering face-piece, level 2) are equivalent masks that differ primarily in their adherence to country standards, with the former complying with the American National Institute for Occupational Safety & Health (NIOSH) 42 CFR 84 standard and the latter with the European EN 149 standard, requiring airborne particle filtering efficiencies of ⩾95% and ⩾94%, respectively. It should be noted that this article focusses on disposable masks that were commonplace during the pandemic; the functionalities of valved respirators or self-contained breathing apparatus are entirely different and exhibit disparate efficacies for self-protection and/or transmission compared to disposable masks, yet such respirators were neither mandated nor in widespread use and are thus not considered in this paper.

community for individuals without symptoms [9]. Moreover, it was suggested that wearing face masks might even promote '*a false sense of security that can lead to neglecting other essential measures*' [9]. This sentiment was reiterated by health officials, stating that the use of face masks in the general population served little benefit, and could even increase the spread of the disease [10]. Advisory reports by the WHO, published during the height of the pandemic in 2020 and 2021, conveyed a similar message, stating that there was '*only limited and inconsistent scientific evidence to support the effectiveness of masking healthy people in the community to prevent infection with respiratory viruses, including SARS-CoV-2*' [11, 12]. Despite the absence of support in favour of community mask wearing, and even voices of concern by leading health authorities and medical professionals, numerous countries quickly made facial coverings mandatory in many indoor settings, including schools, work environments, hospitals and care-homes, general practitioner and dental surgeries, retail outlets, and public transport. Some countries went further by demanding that face masks must be worn outside, a measure justified on the basis of potential and/or likely lapses in 'social distancing', i.e. maintaining a 'safe' interpersonal space, especially in crowded settings. These politically-driven rules effectively reversed years of meticulous pre-pandemic planning overnight. Generally, the public complied with these restrictions, many through a strong sense of fear and anxiety [13], or because people are generally law abiding, if not additionally motivated by legislation (e.g. fixed fines for failure of compliance).

As asserted above, being a respiratory disease infection, it seems reasonable to expect that, if used properly, a face mask will present a barrier to the dispersion of virions (e.g. SARS-CoV-2) into the environment, especially if asymptomatic spread is a significant vector of transmission. The latter consideration aside (addressed later), concerning the barrier effect of face masks, evidence suggests that the airborne spread of the virus is mostly associated with microscopic aerosols ($<5\ \mu$m)—for which face masks present little resistance—rather than droplets [14]. Nevertheless, a number of studies have suggested that wearing face masks can lead to a reduction in transmission, to varying degrees. A WHO-funded systematic review and meta-analysis of transmission prevention measures, including mask wearing, by Chu *et al*, for example, reported a risk difference of transmission of -15.9% to -10.7% for face mask use [15]. In another study, Brainard *et al* concluded that wearing face masks may reduce primary infection risk by probably 6%–15% [16].

Taken at face value, these and other 'mask efficacy' figures suggest that mask-wearing plays a role in reducing infection, albeit marginally. Taking a closer look at such studies, however, reveals several flaws that throw doubt on the reliability of the claimed reduction effects [7]. One example of such shortcomings is associated with studies that extrapolate results from healthcare environments to normal life activities, which are not equivalent settings and thus should not be considered to be interchangeable. Another common deficiency is a lack of consideration of the escape of exhaled air around the periphery of the mask. In a (pre-pandemic) study by Johnson *et al*, the comparative efficacy of surgical and N95 masks to prevent viral (influenza) transmission was investigated using a study protocol that required infected patients to cough through either mask type onto a sampling medium, with subsequent assessment of the deposited viral load [17]. The absence of viral detection in the majority of samples collected through the masks led the authors to conclude that both mask types are equally effective in filtering the virus. As indicated above, however, the study took only direct transmission into account and did not consider side leakage, as is the primary route of exhaled breath when confronted with a frontal barrier. Further, the authors acknowledge other limitations of their study, including a lack of data of infectiousness of individual patients (i.e. whether viral transmission could elicit infection in others) or the use of unsoiled masks (most people during the SARS-CoV-2 pandemic did not replace their mask every five minutes, the latter being the maximum duration of mask use in the study in question). Another (pre-pandemic) study investigating the filtration efficiency of different types of mask, including surgical and fabric-based homemade mask varieties, concluded that the latter offered limited filtration compared to the former [18]. Despite the carefully executed experiments, and like the previously cited work, many aspects of the study are not directly translatable to real-world conditions, including not accounting for peripheral escape, prolonged mask use, or correlation with infectiousness. A major limitation in the filtering capability of face masks due to side-stream leakage was demonstrated in a laboratory setting using tracer particles, whereby the authors concluded that the '*passage of inspired air around the periphery of two types of face masks appears to circumvent the masks' ability to screen airborne contaminants*' [19].

The aforementioned meta-analyses similarly have several limitations, such as a lack of consideration of context, which includes the effects of other preventative measures or frequency of contact with infectious individuals, amongst others. Despite the comprehensive and meticulous meta-analysis presented by Chu *et al*, for example, their assessment of the efficacy of mask-use in preventing viral transmission is based on '*chance of viral infection **or transmission***' (bold added by us for emphasis) of 17.4% without mask-wearing compared to 3.1% with masks, whereby the authors categorize the certainty of this estimate as low, stating that '*confidence in the effect estimate is limited; the true effect could be substantially* *different from the estimate of the effect*' [15]. Besides the overall low absolute risk associated with not wearing a mask, according to the numbers presented by Chu *et al*, their estimated value not only includes risk of viral infection, but also *chance* of transmission, thus the explicit benefit of mask-wearing in preventing infection cannot be deciphered from the data at hand. The study by Brainard *et al*, which is another careful meta-analyses of related scientific literature on mask use, claims that '*wearing face masks may reduce primary respiratory infection risk, "probably" by 6%–15%*', as alluded to above [16]. Again, besides the contextual deficiencies in the analysis, as openly discussed by the authors in their paper, these estimates are generally low and hardly warrant justification of overreaching political mandates on entire populations. Another systematic review and network meta-analysis of pre-COVID randomized control trials (RCTs) to explore mask efficacy by Tran *et al* indicated a marginal benefit of wearing face masks for not contracting influenza-like illness, albeit without statistical power and with limitations due to unknowns relating to other personal protective measures undertaken by individuals within the different cohorts [20].

It is beyond the scope of this perspective to critically appraise all mask efficacy studies or meta-analysis reports, but similar limitations to those discussed above are persistent throughout the scientific literature on such studies. Consequently, it is not surprising that related research initiatives have drawn contradictory conclusions, including several studies reporting that face masks do not result in any significant reduction in transmission under real-world conditions. A Danish clinical trial on the prevention of SARS-CoV-2 infection through mask-wearing, for example, reported that infection numbers were equivalent in the mask and no-mask cohorts, with overall low rates of 1.8% and 2.1%, respectively (total cohort size of $n = 4862$) [21]. A Spanish retrospective population-based study on children—widely considered as members of society most negatively affected by COVID-19 restrictions [22, 23]—assessed data from almost 600 000 school pupils aged 5 (no mandatory face masks) and 6 years (with mandatory face masks) and found no significant differences in SARS-CoV-2 transmission in relation to face mask mandates [24]. In other research, also undertaken in Spain, Marks *et al* examined various factors potentially affecting transmission of SARS-CoV-2, including mask use, reporting no observations relating to risk of transmission associated with reported mask usage, although the authors acknowledge the deficiencies in the analysis due to the lack of data on mask type [25]. A retrospective study on mask mandates and their use in the general population across the United States drew similar conclusions that these measures were not observed to be associated with reduced spread of SARS-CoV-2 [26]. Further, a report on a systematic review of 14 RCTs to evaluate the effectiveness of personal protective measures, including mask-wearing, found no evidence for a substantial effect of mask use on the transmission of laboratory-confirmed influenza [27]. Additional anecdotal evidence that mask-wearing does not prevent transmission comes from the observation that the reintroduction of face mask mandates in countries where COVID-19 incidence numbers were rising had no measurable impact on reducing the upward trend in cases.

A review by Matuschek *et al* explicitly highlights the difficulty in associating mask-use with viral transmission due to multiple confounding factors, including that face masks do not offer any major protection (barrier) to aerosols, they are often improperly used and infrequently exchanged, and, as mentioned above, they might give the wearer a false sense of protection, which may lead to a reduction in social distancing or other personal protective measures [28]. In relation to the latter, the contrary might also be the case, i.e. that mask advocates are more likely to adhere to other protective actions—either through caution or compliancy—such as over-zealous social distancing or self-isolation, thereby reducing contact with infected individuals and consequently lowering their overall risk of viral exposure. Finally, a recent article published in the Cochrane Database of Systematic Reviews explored the efficacy of mask-use based on 78 RCTs involving over 600 000 participants. In their review, Jefferson *et al* found that the use of face masks—specifically, medical/surgical masks and N95/P2 respirators—makes little or no difference to the outcome of influenza-like or COVID-19 illnesses, with no statistically significant differences between mask use or non-use being evident [29].

Clearly, the factors influencing infection are manifold, making direct associations between mask use and viral transmission difficult, with empirical data from simulated or laboratory-based studies not accommodating all physical or social effects of mask-wearing, and meta-analyses of epidemiological data largely relying on self-reporting of mask use and other personal protective measures. Mandating community mask-use based on flawed and inconclusive studies is therefore unscientific and, as discussed below, unethical.

3. Justifying community masking due to asymptomatic transmission

A prevalent justification for masking healthy populations is the notion of asymptomatic or pre-symptomatic spread of SARS-CoV-2, i.e. the situation in which individuals infected with the virus are not presenting symptoms—thus unaware that they are infected—and are therefore unwitting viral vectors as they go about their daily business. Viral transmission via this scenario has remained a major and persistent concern, with suggestions that more than one-third of people infected with SARS-CoV-2 are asymptomatic [30]. This high proportion has been frequently yet falsely interpreted as being synonymous with the incidence of transmission by non-symptomatic individuals, but the evidence in the literature for true asymptomatic spread is limited and generally of poor quality. Pivotal to this argument is the question of 'viral load', i.e. the number of virions an infected person is hosting and thereby potentially shedding into their immediate environment, with a logical assumption that the higher the load, the greater the spread. People testing positive who show no symptoms must have a low viral load, and hence are unlikely to be involved in any significant transmission of the virus. Viral load is generally quantified based on cycle threshold (CT) values used in reverse transcription polymerase chain reaction (RT-PCR) tests, the foremost approach for determining SARS-CoV-2 infection, with samples commonly collected by swabbing mucus in the nasal cavity and/or laryngeal region of the throat. According to this procedure, when the system is adequately calibrated [31] the detection of viral presence after a low number of cycles (i.e. a low CT value) signifies a high viral load compared to a low viral load that requires more cycles for the virus to be detectable.

In considering different modes of transmission it is important to differentiate between asymptomatic, i.e. people who test positive for COVID-19 but never present any symptoms (non-symptomatic), and pre-symptomatic, i.e. the early phase of infection before any symptoms manifest, as the overall viral load may generally vary between these two cases. Making this differentiation from the published literature is challenging, however, as many studies examining viral load between symptomatic and asymptomatic individuals testing positive for COVID-19 lack a follow-up, i.e. an examination of whether the latter cohort was merely pre-symptomatic at the time of testing. Indeed, this phenomenon is a common limitation of many meta-analyses papers, as highlighted by He *et al*, who assert that '*nearly half of the patients who have no symptoms at the screening point can develop symptoms during follow-up*' [32]. Further, people can still test positive long after symptoms have disappeared, because of residual virus fragments still being detected in PCR tests. Consequently, the number of cases of people who are truly asymptomatic is uncertain but definitely low, with meta-analysis studies placing this value as one-in-five or one-in-six [33, 34]. Even these values may be overestimated owing to various limitations in the studies, e.g. incomplete symptom assessment, ambiguity in testing (a positive test does not mean that a person is infectious or hosts the live virus), a complete lack of public tests for the live virus, and lack of follow-up [35] or high CT values (>30) used in RT-PCR tests. In contrast to incidence figures derived from meta-analyses, which pool data from widely inhomogeneous studies of heterogeneous populations and suffer from the mentioned deficiencies, individual studies on well-defined cohorts provide more accurate insights. Data published by Rivett *et al,* based on a SARS-CoV-2 screening programme of healthcare workers at the start of the pandemic, showed that only 3% of workers tested positive in the absence of symptoms, and, moreover, only 0.5% (or one-in-two-hundred) were identified as truly asymptomatic carriers of SARS-CoV-2 (notwithstanding false positives in both cases) [36].

Returning to the question of viral load and the associated degree of potential transmission, accurate figures that distinguish symptomatic and asymptomatic individuals are lacking in the scientific literature due to the limitations mentioned above. A meta-analysis by Zuin *et al* found no differences in the viral loads between symptomatic and asymptomatic subjects, yet their definition—and thereby inclusion criteria—of asymptomatic patients was '*those that did not have symptoms at the time of swab testing and/***or** *did not develop symptoms afterwards*' (bold added by us for emphasis), thus whether individuals assigned to this group truly never presented symptoms is unknown [37]. Again, considering individual studies as opposed to meta-analyses, there is evidence that viral load in truly asymptomatic individuals is considerably lower than in symptomatic or pre-symptomatic individuals. In a small study of a SARS-CoV-2 outbreak in a clinical setting, as reported by Schwierzeck *et al*, the CT values of those patients presenting typical COVID-19 symptoms were significantly lower than those without symptoms, which the authors attributed to high viral shedding [38].

If, as is evident, the majority of cases attributed as asymptomatic are indeed only pre-symptomatic, then the notion of asymptomatic spread as a major contributing factor in prolonging the pandemic must be revisited. Indeed, pre-symptomatic people may be infectious for one or two days prior to developing the illness, but transmission during this period is estimated to be low, with one study indicating that it accounts for approximately only 6% of all transmissions [39]. Once symptoms develop, most sensible individuals will isolate at home to convalesce, thereby reducing their potential for widespread viral transmission. Taken together, and given the major uncertainty in the existence of significant asymptomatic transmission, mandating healthy people to wear face masks based on arguments of asymptomatic spread is tenuous at best and certainly needs to be re-evaluated.

4. Are face masks benign?

At the start of the pandemic, when data supporting evidence for the efficacy of face masks in providing a significant protection from SARS-CoV-2 infection was lacking, a common and prevailing belief was that they do no harm. This was used as a popular argument in favour of mask-wearing, along the lines of '*better safe than sorry*'. But is this truly the case? As with other measures introduced in efforts to stem the pandemic, such as regional or national 'lockdowns' that have been since posited to do more harm than good [40, 41], taking overhasty action based on an assumption of benevolence can backfire and precipitate further damage. In the case of mask recommendations or mandates, harms include physiological and psychological repercussions, as well as environmental impacts, as will be explored here.

4.1. Physical harms

The first obvious question to address is whether face masks are truly innocuous from a physiological perspective, i.e. is there a risk that wearing a mask can have a negative impact on the physical health of the wearer? The answer to this is multifaceted and depends on many factors, including period of continuous use (i.e. duration of the associated potential hazard), frequency of reuse (i.e. accumulated exposure to a soiled mask), and mask type (i.e. cloth versus surgical or N95/FFP2 masks). Possible deleterious effects of mask-wearing are predominantly associated with prolonged inhalation of nocuous agents, including a modified composition of inhaled air, hazardous volatile substances, micro-plastics and fibers stemming from the mask materials, or bacteria and/or fungi accumulated on the mask that are liberated when breathing in.

Returning to the issue of mandates, specifications of the required mask type have played a central role in masking policies in certain countries. Germany and Austria, for instance, redefined their mask mandates as the pandemic progressed to permit the use of only surgical or FFP2 masks in specific settings, sometimes exclusively the latter mask type. These mandates were seemingly made, in part, based on the outcomes of mask efficacy studies, such as those cited in the previous sections, that compare the filtering capabilities of different mask types, with the simple cloth mask universally performing worst (notwithstanding the aforementioned shortcomings of these appraisals), but with a complete disregard of numerous bodies and committees recommending their limited use in working environments, when necessary, due to negative consequences of prolonged wearing. As an example of the associated burden, a sales clerk at the grocery shop wearing an FFP2 mask uninterrupted during an 8–10 h shift for five to six days a week will incur a notably greater exposure to potential negative side-effects than a customer wearing a cloth mask who is grocery shopping for 30 min once in a week. Indeed, mask-wearing in vocational (or educational) settings represents prolonged situations of considerable burden. Other issues that factor in to the degree of encumbrance include the health status (physical and mental), age and maturity of the wearer, amongst other considerations, which all play into the potential for harmful effects.

A study by Spira investigated the association of face mask compliance against morbidity and mortality rates in the 2020–2021 winter in Europe [42]. Comparisons showed that countries with high levels of face mask compliance had similar or even greater numbers of COVID-19 cases or deaths than those countries with low face mask usage. Thus, the universal widespread use of face masks does not appear to reduce SARS-CoV-2 transmission. Moreover, the data indicated a moderate yet statistically significant positive correlation between face mask usage and deaths in Western Europe, i.e. that masking was associated with unintended harmful consequences. In agreement with this, a more recent study showed significant increased deaths in specific counties in the US state of Kansas that mandated face masks compared to those that did not [43]. It is suggested that this could be a result of the deep inhalation of '*hypocondensed droplets or pure virons caught in face masks*', in other words, breathing in highly concentrated viral particles that have accumulated on the inner surface of the mask (through exhalation by the host) and become intermittently liberated with inhaled air passing through the mask, thereby exacerbating viral exposure and its ensuing effects.

A number of studies have indicated that acute physiological harms associated with wearing face masks are generally mild to moderate. These include headaches and/or fatigue [44–46], skin and/or eye irritation and dryness or respiratory distress [46, 47] and dermatitis [48, 49], and an increase in the risk of falls and accidents (e.g. because of glasses steaming-up and/or a reduction of the lower peripheral visual field) [50]. Another harmful effect has been linked to the rebreathing of the air in the 'dead space' of a face mask, i.e. the air that stagnates in the mask between breaths. This has been shown to cause elevated transcutaneous carbon dioxide values and lower oxygen availability [45, 51], which can lead to short-term confusion, disorientation, impaired cognitive abilities, and drowsiness, symptoms that have been collectively referred to as mask-induced exhaustion syndrome (MIES) by Kisielinski *et al* [45]. More recently, Kisielinski *et al* reported a systematic review with meta-analysis demonstrating that masks interfere with O_2-uptake and CO_2-release and providing evidence that masks lead to adverse physio-metabolic and clinical outcomes, thereby validating MIES, especially for vulnerable groups, such as children, pregnant women, the elderly, and people suffering from illnesses [52]. With regards to issues of CO_2 release, it has been reported that mask wearing rapidly leads to children inhaling CO_2 at concentrations above the accepted safe levels [53], the long term implications of which to children's health are unknown. The effects of CO_2 toxicity as a result of mask wearing, particularly for pregnant women, children and adolescents, have been recently and comprehensively reviewed, in which a number of issues associated with adverse effects and risks related to extended mask mandates were raised, including increased risk in stillbirths and reduced overall cognitive performance in children [54]. Sukul *et al* have also highlighted the potential problems of rebreathing, showing that the exhaled breath profiles of several endogenous volatile compounds, i.e. compounds stemming from the physiology, exhibit physio-metabolic effects, such as hypoxia, oxidative stress, hypoventilation, compartmental vasoconstriction, altered systemic bacterial activity and energy homeostasis [51]. These effects were observed to be more noticeable in the elderly (60–80 years), as well as for those wearing FFP2 masks compared to surgical masks.

In addition to the effects associated with rebreathing during mask-wearing, the chemical composition of inhaled air can also be influenced at trace level concentrations through contributions from volatile organic compounds (VOCs) released from the masks. These VOCs can originate either from constituents of the mask fabrics, specific chemical additives (e.g. colorants), or as by-products or residual components from the manufacturing and/or post-production treatment processes. When a mask is exposed to elevated temperatures and/or humidity conditions—as occurs through normal, prolonged breathing through the mask fabric—this can act to liberate constituent volatiles, which are subsequently inhaled by the mask-wearer. Exposure to these VOCs via dermal uptake through direct contact with the skin is also an issue of concern. In an analytical study conducted on FFP2 and KN95 masks, Kerkeling *et al* discovered the presence of toluene (a compound with acute toxicity capacity) in all of the 47 masks that were examined, as well as other compounds, such as aldehydes and siloxanes [55]. Xie *et al* reported the detection of twelve phthalates in 56 masks of various types sourced from different countries and estimated that 89.3% of the mask samples exhibited potential carcinogenic effects to humans, highlighting a pressing need to regulate materials and levels of additives of face masks [56]. Another study on a variety of different disposable masks found that 12 of the 16 masks investigated contained organophosphate esters, a chemical compound category of concern due to their toxicological effects, including endocrine disruption, negative impact on reproductive function, and suspected carcinogenic potential, although their concentrations were deemed to present a low risk for negative impact to the wearer [57]. A study by Liu *et al*, reporting the non-targeted analysis of volatile chemicals in 60 medical masks, observed the presence of 69 different VOCs, amongst them alkanes, esters, benzenes and alcohols, with 12 compounds considered high-risk for negative health impact [58]. Finally, a study by Jin *et al*, this time focusing exclusively on surgical masks, found substances such as naphthalene (a suspected carcinogen belonging to the class of compounds known as polycyclic aromatic hydrocarbons, or PAHs) and di(2-ethylhexyl) phthalate (a potential endocrine disruptor), amongst others, to be present at notable concentrations in many of the masks under investigation [59]. The authors further explored measures to reduce the VOC load of the masks, reporting that a 60 min heat treatment at 50 °C reduced the total VOC content by about 80%, which the authors suggest is easily achievable by most mask wearers by use of domestic ovens. Nevertheless, even if people are made aware of these hazards, it is doubtful that many would undertake such a laborious procedure or be willing to use an oven for such a seemingly overzealous purpose.

Beyond the negative consequences associated with a compromised air supply or exposure to exogenous chemical constituents from the masks, inhalation of physical entities might also pose a risk. The presence of bacteria and/or fungi on face masks through their accumulation after repeated mask use represents an unnatural burden to the respiratory system. Studies undertaken to examine the potential pathogens on soiled masks have observed the presence of greater bacterial colony numbers on the face-side of masks compared with the outer side, although the reverse was true for the case of fungi, indicating that the latter are indeed filtered from environmental sources during inhalation [60]. Species of bacteria isolated from the inner surface of masks included non-pathogenic microorganisms, as well as antibiotic-resistant and/or pathogenic species, amongst them *Bacillus, Staphylococcus, Acinetobacter, Bacillus*, and *Aspergillus* [60, 61].

Apart from exposure to microorganisms, another consideration of potential harm associated with (prolonged) mask-wearing relates to the inhalation of micro-fibers and micro-plastics from the materials of the mask [62, 63], whereby such particles have been reported to have genotoxic potential [64] and exposure to them has been linked to respiratory inflammation, amongst other negative consequences for health [65]. Systematic studies on this risk are lacking, thus the degree of exposure to micro-particles through mask-wearing is impossible to estimate based on current data. A study by Sullivan *et al*, however, demonstrated that particles can be liberated from face masks with little agitation, thereby raising concerns of the quantities of (nano-)particles being inhaled by users, especially for those who are required to wear face masks for many hours, such as in occupational settings [66]. In a laboratory-based study by Li *et al*, the amount of micro-plastics accumulated in ambient air passing through different mask types was investigated [67]. While that study focused on the efficiency of masks to filter airborne micro-plastics present in the ambient environment, the accumulation of high numbers of particles and fiber-like micro-plastics—to varying degrees—at the downstream end of all mask types tested indicate that either they offered poor filtering efficiency for ambient particles, or that the micro-plastics collected included (or were potentially even dominated by) fibers and plastics derived from the masks themselves; the study made no differentiation of the sources of these particles. The science is unclear with this regard, but given the risk of inhaled micro-plastics from mask fabrics potentially eliciting negative effects on the respiratory system, or even through dermal uptake through skin contact [65], it would be judicious to err on the side of caution and minimize mask-use until there is compelling evidence that dispel this concern.

4.2. Collateral damage

The focus of this perspective is on the inefficacy of masks to stem viral spread and the associated physical harms when mandating mask wearing to healthy populations. The 'collateral damage' of mask mandates is not limited to physical harms, however, but extends to potential psychological damage and social impairments, as well as negative impacts to ecosystems. These issues are highlighted in the following, with assertions made on rational and logical considerations and assumptions, supported by evidence from the scientific literature, where appropriate. The extent of repercussions to child development, mental health and environmental damage is expected to emerge only in the coming years and decades, thus full treatments of these topics are left to experts in the respective fields as the full consequences manifest and become apparent.

Psychological harms and adverse social outcomes are less tangible than physiological ones, and some are less immediate, but negative impacts on mental development and health associated with widespread face mask wearing, especially in children, are generally recognized amongst experts. It is often argued that even if they help little to limit transmission, masks offer a positive psychological effect by making people feel safe (or safer), for both the wearer and observer alike, thus allaying fears and reducing anxiety associated with the threat of the virus. Although this assertion will certainly apply to some parts of the population, the opposite will be the case for other members of society who experience higher anxiety through the constant sight of fellow masked citizens. Accordingly, justifying mandatory mask-wearing on the basis of offering visual reassurance of apparent safety has an undeniable ethical implication, because coercing or forcing a person to undertake something they would otherwise choose not to, such as to wear a face mask, infringes on a person's freewill and their right to bodily autonomy. Nobody should be forced to cover their face to make another person feel safe. Moreover, nobody should be depicted as being selfish or lacking in solidarity through a refusal of compliance—with 'mask refusers' frequently being at the receiving end of verbal and sometimes physical abuse throughout the pandemic, notwithstanding partial exclusion from society through a refusal of entry to shops, work or other public buildings—nor should such people be isolated as scapegoats when mask mandates fail to achieve results. Before the pandemic, mask-wearing by individuals with infections was—and still is—considered an act of courtesy in many societies with the intention of preventing transmission to fellow co-workers or travelers. As outlined above, however, in the case of COVID-19, the notion of asymptomatic spread is questionable and those with symptoms will inevitably remain at home to recover. Thus, the justification of mandatory masking on the grounds of courtesy or 'just in case' is tenuous, at best. The wearing of a face mask must remain an individual and informed choice based on reasoned advice, rather than on fear, anxiety, shame or coercion. As addressed above, such arguments represent a double-edged sword: on the one hand, mask wearers might consider their mask as a shield that protects them from infection, with a corresponding lapse in taking other cautionary measures; on the other hand, persistent visual cues of ubiquitous mask-wearers can trigger anxiety in individuals who are especially fearful of infection, which compounds the psychological harm already elicited through the pandemic and the ensuing persistent media coverage.

Arguably, children have been the most affected by mandatory mask wearing. It is commonly recognized that face-to-face interactions are essential for children's social, educational and emotional development. Green *et al* have discussed the potential negative development in babies to human connection and attachment [68]. These concerns are partly confirmed in a study by Deoni *et al*, who examined the cognitive abilities of infants aged 0–16 months and reported that '*infants born during the pandemic exhibited significantly reduced verbal, nonverbal, and overall cognitive performance compared to children born pre-pandemic*', which was found to be not attributable to maternal stress, but equally was not exclusively associated with mask-wearing, thus the contribution of masks to this decline cannot be derived from these data [22]. Anecdotally, delayed and impaired development in pre-school children during and since the pandemic compared to pre-pandemic expectancy has been corroborated in observations of a child psychologist consulted with on this matter during the preparation of this article (unpublished observations). In schools, children interact with their teachers and teaching assistants not only verbally but also through facial expressions. The elimination of visual cues, potentially coupled with a reduction in clarity of speech by the educator or fellow pupils, significantly limit communication and hence children's progress, especially in infants and young children. Consideration of this disruption to the learning environment together with the potential physical effects of forcing children to wear masks for long periods (e.g. associated with rebreathing through masks, as discussed above) means that a request or demand to mask children and teachers in school classrooms is unjustified and unethical.

The lack of social contact for all face mask wearers, children and adults alike, could potentially lead to depression, and withdrawal from society, particularly for those already suffering with mental health issues. This is because, to some extent, face masks present a physical sign to inform people of a present danger. This causes anxiety for many, especially in view of a reduction in our ability to read emotions via facial cues through visual obstruction of the face, as has been demonstrated in both infants and adults [69, 70], although this might be compensated by contextual cues [71]. Finally, members of the public that have impaired hearing or are deaf might be particularly negatively impacted through mask-wearing through the absence of visual cues during conversation, thereby compromising their ability to interact fully in society.

Although the potential harms of face mask mandates center on the health and wellbeing of the individual, other 'collateral damage' must also be considered in weighing up the argument in favor of such measures. This includes environmental issues relating to the use of valuable resources in mask production and the fate of masks at the end of their service. With the production of disposable plastic face masks in China alone being of the order of 200 million per day, and with billions of face masks being discarded worldwide on a daily basis [72], this raises the prospect of significant environmental damage owing to the release of various chemical pollutants into the ecosystem. Consequently, there is a pressing need for an in-depth investigation of the long-term environmental impact of the pandemic resulting from discarded face masks.

Effects of masks on the environment have been summarized in several general articles and treatises [45, 73–75], hence only brief details are given here. A study by Sullivan *et al* has highlighted the potential pollution by micro- and nano-sized particles, mainly plastic fibers and silicate grains, but also heavy metals (Pb, Cd and Sb) and organic pollutants, being released from disposable plastic face masks that are exposed to water, as is the case when these enter our waterways, seas and oceans [66]. Another study investigated and demonstrated the potential contribution of single-use surgical masks to pollution in respect to dye carriers in the aquatic environment [76]. In agreement with the study by Rathinamoorthy and Raja Balasaraswathi, a detailed investigation of the structural properties of disposable face masks has shown that a mask can release between up to 35 or 150 mg of microfibers in wet or dry states, respectively [77]. The volatile constituents of masks or their additives also present a concern as these compounds, such as the aforementioned organophosphate esters, are liberated from disposed masks into the environment [57]. In addition to the direct negative impacts to our natural world, even these can ultimately have consequences for people, as highlighted in a paper by Aragaw, who asserted that the ingestion of fabrics from discarded masks by higher organisms in aquatic life has implications for the food chain and consequently human health for those consuming affected fish [78].

When one considers the billions of masks that have been thrown away in the past three years, the resulting amount of nano- and micro-particles that have entered the environment—and will continue to do so in the coming years and decades—is significant and largely irreversible. Repeating this disastrous practice through further mask mandates without viable contingency measures would be an act of gross negligence to our fragile ecosystems.

5. Concluding remarks

At the start of the COVID-19 pandemic, mandates to wear face masks to limit the transmission of SAR-CoV-2 in general, healthy populations were imposed based on assumptions rather than on scientific evidence. Since then, numerous studies have investigated the efficacy of face masks balanced against potential and actual harmful effects in different areas, hence we considered that it is important and timely—if not long overdue—to revisit the rationale for face mask use. This perspective draws from the body of scientific literature to evaluate the rationale for wearing face masks as an effective measure to prevent the spread of SARS-CoV-2 and thereby contribute to stemming the pandemic, or indeed future pandemics. The scientific evidence for face masks to limit transmission is contradictory and controversial, and studies addressing the true contributions of masks in preventing or limiting pathogen transmission are presently lacking. RCTs on mask efficacy were not conducted during the pandemic, but a survey of the literature indicates that there is no strong support to show that face masks significantly reduce infection or transmission. Some studies have even indicated that the use of face masks potentially increases transmission and can lead to physical harms, as well as have negative impacts on psychological wellbeing and our environment.

The mask debate need not—moreover, *should not*—be an emotive issue. As scientists, we must look at and interpret the data at hand and draw impartial and evidence based conclusions to inform decisions. Science is not a rigid discipline, but an evolving enterprise in which theories can and often do change through new discoveries and knowledge. Recommendations should not be biased towards one objective but should be based on a balanced consideration of all benefits and repercussions. Given that face masks are not benign and at best have only a limited effect on reducing viral transmission, it is time to re-evaluate mandates forcing people to wear face masks in any setting. Based on the balance of evidence, as detailed in this perspective, we conclude that the downsides of mask-wearing in relation to physical and psychological health, as well as the negative environmental impact, greatly outweigh any potential benefits. Furthermore, given that the majority of the scientific evidence suggests that the wearing of a face mask has no impact on preventing infection or transmission of SARS-CoV-2, mandates to enforce mask wearing are unethical.

Data availability statement

No new data were created or analysed in this study.

Disclaimer

The authors would like to assert that this perspective solely represents the evidence drawn opinions and views of the authors and not the positions or policies of their respective institutions, or those of the journal or its publisher. The extensive period of review of this perspective, from the first submission—on Armistice Day 2022—to its publication more than six months later, perhaps reflects the current fragile state of affairs in science, whereby the consensus narrative should remain unquestioned and counterarguments are unwelcome and should be censored. In the intervening six months since our submission, a number of peer reviewed papers have been published that have served only to strengthen the main conclusions reached in our original perspective, and none to our knowledge have been published that provide any evidence that counter them. Nevertheless, it is hoped that this article is an impetus for further scientific research and discourse on this topic, with the authors encouraging the dissemination of new evidence on either side of the 'mask debate' that either refute or corroborate the assertions made in this paper.

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