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The efficacy and effectiveness of face masks and their role in minimising the spread of a global pandemic.

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Given that up to 120 global governments[1, 2] are urging their citizens to wear masks whenever possible, it is natural to inquire how effective they really are in stopping the spread of SARS-CoV-2 (and other such pathogens).

Before discussing their efficacy and effectiveness in a wider setting, we must first understand how various common types of masks work (cloth, surgical, and N95). In essence, they all work in a similar way – by blocking thousands of respiratory droplets released when people cough, sneeze, or talk.[3, 4] For those who are infected with COVID-19, these droplets may well contain as many as 200,000,000 individual viral particles.[5, 6] The method of blocking these droplets, however, differs between cloth and surgical masks, and N95 masks. Whereas the former two function by simply 'catching' droplets in multiple layers of meshed fabric, the latter employs a more ingenious method.

Particles ≥1μm in diameter have sufficient inertia to not have their straight path deviated by collisions with air particles. As many layers are present in the N95 mask, the probability that such a particle will impact a fibre is close to 100% (capture by inertial impaction: figure 1).[7] When particles of this size or smaller touch a fibre, they tend to 'stick' to it, and do not return airborne, due to the action of Van der Waals forces of attraction. Particles ≤0.1μm in diameter, however, are so small that they exhibit Brownian motion due to collisions with the air particles surrounding them[8]. The random nature of this motion also brings with it an almost 100% probability that the particles will impact a fibre (capture by diffusion: figure 2).[7]

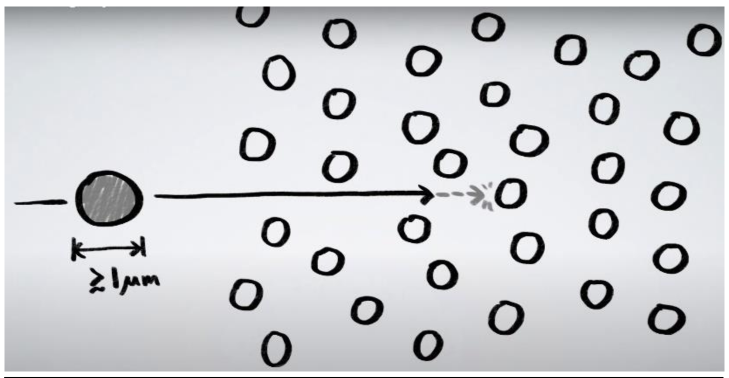

Figure 1: Capture by inertial impaction[7]

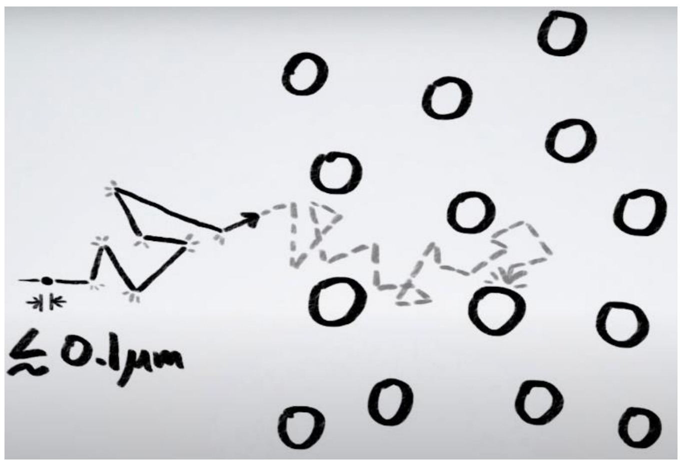

Figure 2: Capture by diffusion[7]

The most difficult size of particle to capture is between these two extremes – those particles ≈0.3μm in diameter. Particles of this size do not engage in Brownian motion, but, rather, move in tandem with the motion of air around fibres in the mask. As such, were this to be a cloth or surgical mask, these particles could pass through uncaptured. However, every fibre of an N95 mask is an electret (has a permanent charge dipole). Via the process of charging by induction[9], even uncharged particles can be electrostatically attracted to the source of a charged field. As such, even particles of this size can be captured (figure 3), and at a rate about 10x that of uncharged fibres; this rate gives rise to the number succeeding the 'N' i.e. N95.[9]

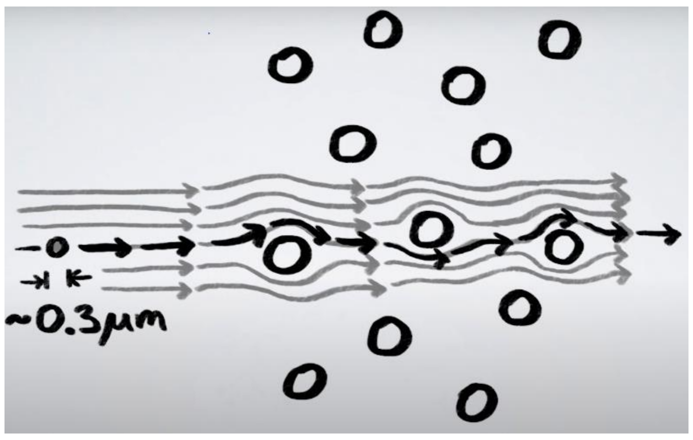

Figure 3: Motion of ≈0.3μm particles around uncharged fibres

These differences in the methods of capture employed by each mask type are the key reason behind their individual efficacy. However, in practice, masks tend to fall short of their filtration effectiveness rating e.g. N95 masks actually filter out ≈90% of incoming aerosols down to 0.3 μm.[10, 11] This value is still much greater than that of surgical and comparable cloth masks, which have been estimated to be 67% effective.[12] It should be noted that this is, in part, due to the fact that N95 masks are designed to be worn with a very close facial fit, whereas surgical and cloth masks are designed to be comparatively loose fitting, thereby allowing the movement of particles around the peripheries of the mask.[13]

Multiple studies have also suggested that surgical masks tend to have a higher filtration rate than cloth and fabric masks [14, 15, 16, 17, 18], and that, in some cases, cloth masks can release particles of their own[19], or may even increase the rate of infection[17] if not washed properly, or reused.

Though each variety of mask discussed may protect the wearer (and those surrounding them) to varying degrees, the general consensus is that all masks (discussed above) are beneficial in reducing the number of droplets and particulates in circulation. An international study in early 2020 found that surgical masks can efficaciously reduce the emission of influenza virus particles into the environment in respiratory droplets (but not in aerosols)[20]. Similar findings have been observed in a 'real world' setting, using epidemiological data. A recent study published in *Health Affairs*, for example, compared the COVID-19 growth rate before and after mask mandates in 15 states and the District of Columbia. It found that mask mandates led to a slowdown in daily COVID-19 growth rate, which became more apparent over time. The first five days after a mandate, the daily growth rate slowed by 0.9% compared to the five days prior to the mandate; at three weeks, it had slowed by 2.0%.[21, 22]

Another study looked at coronavirus deaths across 198 countries and found that those with cultural norms or government policies favouring mask-wearing had lower death rates.[23] This has been shown most starkly by comparing the COVID-19 incidence per million population in various different countries, in which the compliance of general public face mask usage is known. Within the first 100 days of research conducted by researchers from Hong Kong, the incidence of COVID-19 in HKSAR (Hong Kong Special Administrative Region) was 129.0 per million population. This in sharp contrast those values of Spain (2983.2), Italy (2250.8), and the USA (1102.8). In the given timeframe, the compliance of face mask usage by HKSAR general public was 96.6% (range: 95.7% to 97.2%).[24] The figures for the other countries discussed pale in comparison; 63.8%, 83.4%, and 65.8% respectively.[25] As such, the researchers concluded that "[c]ommunity-wide mask wearing may contribute to the control of COVID-19 by reducing the… emission of infected saliva and respiratory droplets from individuals with subclinical or mild COVID-19".[24]

Having been provided clear evidence that public mask wearing helps to prevent the spread of viruses (and so slows the propagation of pandemics), one may still wonder what the minimum percentage of the population that must wear a mask is, for them to be overall effective.

Scientists from the UK, USA, France, and Finland complied a model of the COVID-19 pandemic, using a stochastic dynamic network based compartmental SEIR (susceptible-exposed-infectious-recovered) approach, assuming a heterogenous population, and an initial infected population of 1%.
Each node (individual person) can be: susceptible (*S*), exposed (*E*), infectious (*I*), recovered (*R*), or dead (*F*). The rate of transmission per S- I contact per time is given by β (0.155). From *E*, the individual progresses to being *I* and eventually *R* with rates σ (rate of progression, 1/5.2) and γ (rate of recovery, 1/12.39), respectively. Additionally, individuals in *I* are removed from the population (i.e. die of the disease) at rate μ_I (rate of mortality). The locality parameter *p* gives an indication of the lockdown stringency i.e. *p*=0.02 during lockdown, and *p*=0.2 during social distancing phases. This dictates the probability of individuals coming into contact with those outside of their immediate network. Assuming that individuals have around 13 contacts in normal everyday life, social distancing will reduce this to 4 and lockdown to only 2.
Formally, each node *i* is associated with a state X_i, which is updated based on the following probability transition rates:

$$\Pr(X_i = S \to E) = \left[p\frac{\beta I}{N} + (1-p)\frac{\beta \sum_{j\epsilon C_G(i)} \delta_{X_j=i}}{|C_G(i)|}\right]\delta_{X_i=S}$$
$$\Pr(X_i = E \to I) = \sigma\delta_{X_i=E}$$
$$\Pr(X_i = I \to R) = \gamma\delta_{X_i=I}$$
$$\Pr(X_i = I \to F) = \mu_I\delta_{X_i=I}$$

Where $\delta_{X_i=A} = 1$ if the state of X_i is A, or 0 if not, and where $C_G(i)$ denotes the set

of close contacts of node i.

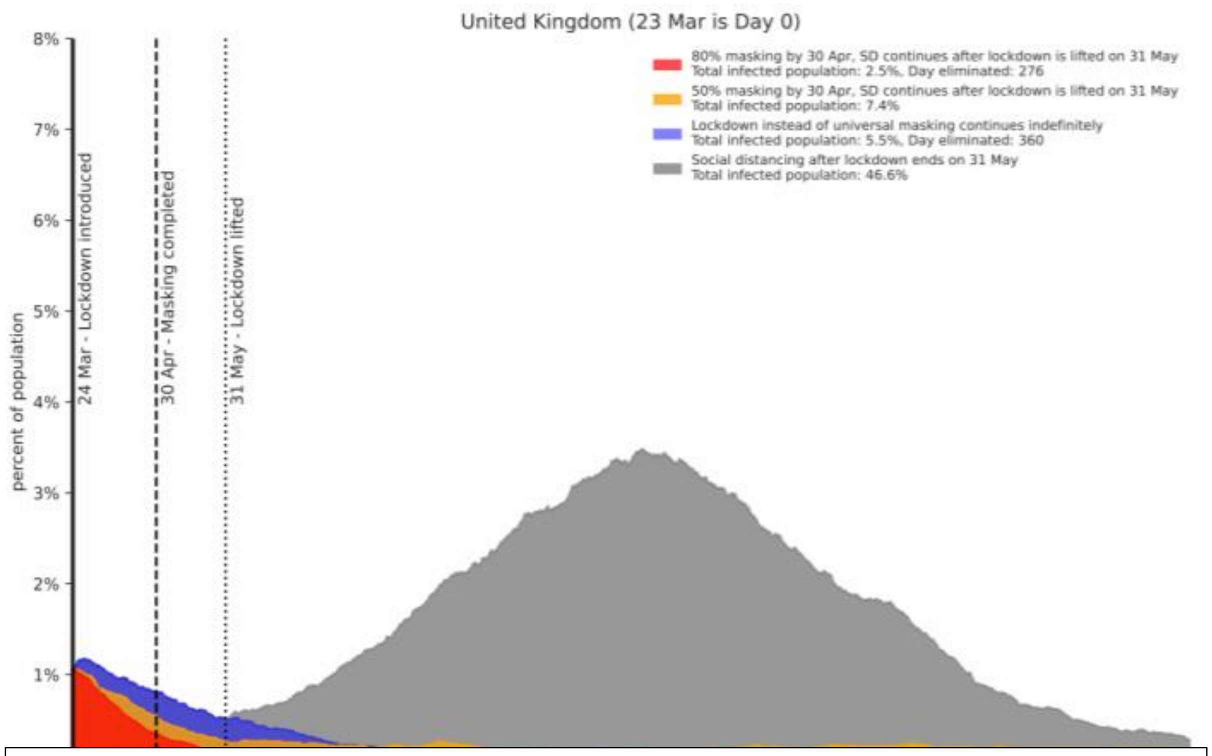

Figure 4: Simulation results for a representative scenario: universal masking at 80% adoption (red) flattens the curve significantly more than maintaining a strict lockdown (blue). Masking at only 50% adoption (orange) is not sufficient to prevent continued spread.[26]

This is corroborated by a study by Yan et al., which concluded that "a sufficiently high adherence rate (~80% of the population) resulted in the elimination of the outbreak (of influenza type viruses) with most respiratory protective devices".[15, 27]

Despite all this evidence regarding the effectiveness of masks, some still believe that they are "[i]neffective, [u]nnecessary, and [h]armful".[28] Though such a perspective may seem ludicrous to us, there are valid arguments to support this notion. In a paper published in *Emerging Infectious Diseases*, researchers from the University of Hong Kong discussed how they found no significant reduction in influenza (and other such pathogens) transmission with the use of face masks [28, 29]. Similar such findings have been arrived at by other scientists, e.g. in the *Annals of Internal Medicine* [30]. Even conceding high mask efficacy, their potential side effects must still be noted. The major side effects of mask wearing have been mentioned in an article published in the BMJ[31]. Of these six, only two have been widely acknowledged, but the remainder (and ways to manage them) should be seriously considered before implementing universal masking policies – (1) Wearing a face mask may give a false sense of security and make people adopt a reduction in compliance with other infection control measures [31, 32]; (2) Inappropriate use of face mask: people touching their masks, not changing their single-use masks frequently, disposing of them correctly, or not washing them regularly, may increase their and others' risks [31, 32, 33]. We must consider both sides of the argument before coming to a definite conclusion.

Despite a few studies having suggest that mask use confers no benefit in stopping the spread of SARS-CoV-2 type pathogens, the majority of more reliable studies, including systematic reviews and meta-analyses, such as that published in *The Lancet*[12], suggest that near universal mask wearing is effective in reducing the spread of pandemics, like COVID-19, thereby minimising the total number of casualties, as well as the associated damage to economies.

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