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The use of face masks during vaccine roll-out in New York City and impact on epidemic control

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ABSTRACT

Face masks were mandated in New York during the first wave in 2020, and in 2021 the first vaccine programs have commenced. We aimed to examine the impact of face mask and other NPIs use with a gradual roll out of vaccines in NYC on the epidemic trajectory.

A SEIR mathematical model of SARS-CoV-2 transmission was developed for New York City (NYC), which accounted for decreased mobility for lockdown, testing and tracing. Varied mask's usage and efficacy were tested, along with a gradual increase in vaccine uptake over five months. The model has been calibrated using notification data in NYC from March first to June 29.

Masks and other NPIs result in immediate impact on the epidemic, while vaccination has a delayed impact, especially when implemented over a long period of time. A pre-emptive, early mandate for masks is more effective than late mask use, but even late mask mandates will reduce cases and deaths by over 20%. The epidemic curve is suppressed by at least 50% of people wearing a mask from the start of the outbreak but surges when mask wearing drops to 30% or less. With a slow roll out of vaccines over five months at uptake levels of 20–70%, NPIs use will still be needed and has a greater impact on epidemic control.

When vaccine roll out is slow or partial in cities experiencing local transmission of COVID-19, masks and other NPIs will be necessary to mitigate transmission until vaccine coverage is high and complete. Vaccine alone cannot rapidly control an epidemic because of the time lag to two-dose immunity. Even after high coverage, the ongoing need for NPIs is unknown and will depend on long-term duration of vaccine efficacy, the use of boosters and optimized dosage scheduling and variants of concern.

1. Introduction

The COVID-19 pandemic has affected the United States (US) severely. New York City (NYC) was one of the first cities to be impacted, with over 200,000 documented cases and nearly 20,000 deaths by June 2020 [1]. Prior to vaccines being available, the COVID-19 pandemic required non-pharmaceutical interventions (NPIs) for control. This includes case finding and isolation, contact tracing and quarantine, social distancing and face masks. Initial guidance from the World Health Organization (WHO) and the Centers for Disease Control and Prevention (CDC) in March 2020 was that masks should not be used in the community, except by symptomatic people [2]. However, in New York State during the first wave, face mask use was recommended on April 3 and mandated in public places from April 15th. By April 2020, the CDC also recommended the use of cloth masks in the community [3]. A WHO-commissioned systematic review and *meta*-analysis which examined data from the experience during SARS, MERS-CoV and SARS-CoV-2 found that medical masks and 12-layered cloth masks reduced the infection risk by 67% on average [4]. This prompted the WHO to review and change its guidance in June 2020 to recommend masks in situations where social distancing could not be practiced.

A compelling argument for face masks is to prevent aerosol or droplet transmission from asymptomatic, pre-symptomatic and mildly symptomatic individuals. Outbreak studies show anywhere from 17.9 to 50% of infected individuals may be asymptomatic or pre-symptomatic and can be infectious in this state [5–8]. Of those who do develop symptoms, viral shedding data suggest that up to 44% of transmissions may occur in the two days prior to symptom

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onset [9]. This means that people may be unaware they are infected with COVID19 at the time they are most infectious, providing a rationale for universal masking.

A face mask may prevent transmission of viral particles by either preventing onward transmission from an infected person (source control), or by protecting healthy people wearing a mask. There is evidence of effectiveness of masks for both indications from randomized clinical trials against other respiratory infections and clinical influenza-like illness [10]. In Missouri, wearing a mask prevented the spread of SARS-COV-2 from two infected, symptomatic hair stylists to 139 customers [11]. In communities at risk or with high burden of COVID-19, universal recommendations for mask use may be an important additional strategy to prevent transmission while the vaccine coverage increase.

Facemasks may be medical devices (medical or surgical masks) or non-medical devices (cloth face coverings or cloth masks). Now, with vaccination programs rolling out across the US, masks and other NPIs are still recommended, particularly as the more contagious newly emerged SARS-COV-2 variants which may escape vaccines, such as B.1.1.7 from the United Kingdom and P1 from Brazil begin to spread in the US [12].

NYC has achieved 57% of the population fully vaccinated, but the CDC removed mask mandates in May 2021 [13]. With the Delta variant causing a resurgence, mask use was re-introduced and the focus is now to increase vaccination coverage, including children, and providing a third dose booster [14]. NYC now strongly recommends masks in indoor settings even if already vaccinated, but has not made it mandatory [15].

We aim to estimate the impact of community face mask use, at varying levels of mask uptake and mask effectiveness during the roll out of vaccination in New York City.

2. Methods

We developed a mathematical model of SARS-CoV-2 transmission for New York City (NYC). NYC was chosen because it had a high burden of disease and good quality reporting of diagnosed COVID-19 cases [1]. The NYC population data were derived from the relevant statistical collection for 2017 [16]. We used an age-structured deterministic model, with 11 mutually exclusive compartments reflecting disease/infection states (see Supplementary Material). Additionally, each of the compartments is divided into 16 age-stratified groups each of 5 years duration, up to the age of 74 plus an additional age group of 75 + years.

The model simulated 700 days using data from the first wave, starting on March 1st, 2020, the time when the first cases were reported in NYC to look at the impact of masks during a vaccine roll out. Data from the first wave were used because complete data, including on mobility, was available for this period. Therefore, the first wave data were used, together with hypothetical vaccine use at that time to evaluate the impact of masks and vaccine on epidemic growth while vaccine coverage is increasing progressively. To provide the initial condition of infected and latent (incubating) people as of the March 1st, we summed all reported cases (48) until March 7th and put them in the symptomatic compartment from the March 1st, to take into consideration delay in detection and notification of the first cases. To estimate the number of latent infections, we used the case notifications from March 1 to June 29 from the New York City government website [1]. In our model, the rest of the New York City population was considered susceptible.

We included the effect of routine disease control interventions such as case isolation, contact tracing and quarantine in the model, to ensure more realistic outputs of the model. We modelled the impact of the lockdown which occurred in New York City with decreasing mobility over time, starting with 10% reduction in mobility during the first wave when the lockdown started, changing to 55% reduction in mobility at the peak of the epidemic and onwards. Those mobility data over time were obtained from a study of mobile phone data that revealed mobility patterns in New York City during the pandemic [17], and this reduction is applied to the contact rates matrix used [18]. Further details of the model and assumptions are available in the Supplementary material.

In the base case scenario, we tested medical masks worn by 50% of the community, with mask wearing commencing early (at the beginning of epidemic activity), to examine the hypothetical effect or early mask use on epidemic growth. The effectiveness of wearing medical masks on disease transmission is estimated to be 67% effective in reducing the risk of infection in the wearer [4]. We tested a range of mask effectiveness in the range of 0 to 96% on the general population to allow for a range of products from poor

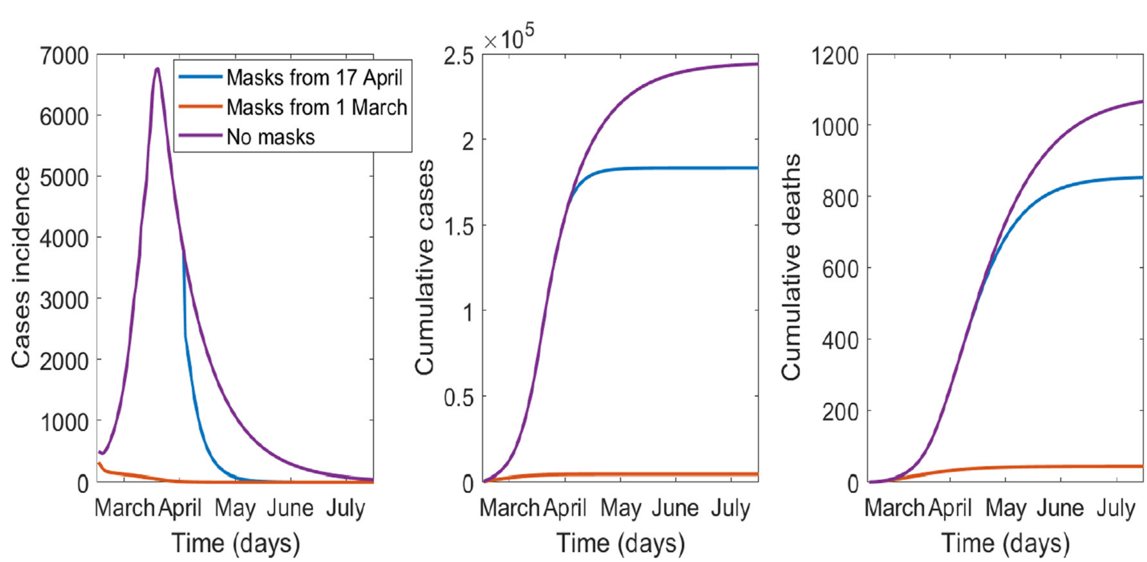

Fig. 1. Impact of early mandated mask use (from 1 March 2020), actual mandated mask use from 17th April 2020 and no masks (lockdown only on incidence of cases, cumulative cases and deaths, in the base case scenario (50% wearing masks).

quality cloth face coverings (0% effectiveness) to N95 respirators (96% effectiveness) [4]. There are no data on cloth masks other than 67% effectiveness for 12-layered cloth masks against SARS [4] and no efficacy (0%) for a 2-layered cotton mask [19]. The use of good design principles, however, can produce effective cloth masks [20]. Given the wide range of home-made cloth designs, ranging from a bandana to custom-designed masks with differing number of layers and differing fabrics we assume a range of effectiveness of 0–96%. We included this sensitivity analysis in the model to addresses the uncertainty around the baseline case estimate of mask effectiveness.

We then compared the epidemic if masks were used pre-emptively and early from the first of March compared to the actual date of mandated masks on the 17 of April. The pre-emptive strategy would be mandated mask use when community transmission was first documented.

We also conducted a sensitivity analysis on the proportion of people wearing masks (0, 20, 40, 60 and 80%).

Finally, we conducted a hypothetical scenario in which the vaccination was delivered with gradually increasing uptake (to mirror the start of the vaccine roll out in 2021). We used the same initial conditions and time window in order to compare the effectiveness of vaccination alone with no other NPIs apart from contact tracing and cases isolation (excluding masks use and social distancing) and with social distancing. We tested the effect of 20%, 50% or 70% of the population being vaccinated in 150 days. We modelled the use of a high efficacy vaccine such as Pfizer or Moderna, which are being used in the US [21,22]. These are 95% and 94% effective against symptomatic infection, and there is 21 days gap between the first and second dose for Pfizer, and 28 days for Moderna [23]. Results show that it takes two more weeks after the second dose to reach the full effectiveness, however there is some evidence of partial immunity following the first dose [24,25]. Furthermore, based on data submitted to the Food and Drug Administration on prevention of asymptomatic infection [26], we conservatively assumed 80% efficacy overall following the second dose (against all infection), based on 65% of infection being symptomatic [27]. The vaccination doses are distributed to the population first to people 65 + years old, and then to the rest of the population 18-to 64 years old. In those two age groups the vaccines get distributed within age-groups following the distribution matrix, which is recalculated every day, with the weighted proportion of each age group, to take into consideration people developing symptoms or dying.

3. Results

Supplementary Figure A shows the unmitigated epidemic with no mandated face mask use or vaccine, but including testing, tracing and reduced mobility over time. There is good model fit to actual reported cases (shown in Supplementary Figure A), validating the model. The best fit model shows that by the first week of March 2020, when 48 cases were reported, there were already 960 undiagnosed or latent cases, which suggests reported cases were 5% of total infections at that time.

The peak of the first wave in NYC was on April 6th, so the mandate for masks occurred after the peak. If masks were used pre-emptively from the 1st of March instead of the 17 of April (Fig. 1), it would have had a substantial additional impact, with a total of 4419 cases and 43 deaths. However, even late use of masks still reduced the total number of cases and deaths compared to no masks, by 27.5% and 23.1% respectively, from 244,869 to 177,479 for cases and from 1,084 to 834 for deaths.

In Fig. 2, we show the sensitivity of the results to a range of mask effectiveness values with 50% of the population wearing a mask. For masks that are 44%, 67% and 96% effective, the number of cases and deaths respectively were 12,860, 4,419 and 1,677 cases and 84, 43 and 28 deaths. For a mask that was 20% effective, we found a reduction in cases from 244,869 to 55,874 (Fig. 2).

The model is sensitive to the proportion of the population wearing masks (Fig. 3). The epidemic curve is suppressed by at least 50% wearing a mask but begins to surge when mask wearing drops to 30% or less. If 80% of the total population wear medical masks, there is an 80% reduction in cases and 50% reduction in deaths compared to base case scenario of 50% mask wearing. If the percentage of medical mask wearing decreased to 20%, there is still 85% reduction in cases and 83% in deaths compared with the no-mask scenario.

Finally, we show results of vaccination alone without masks to control the outbreak (Supplementary Figure B) or in conjunction of social distancing (Fig. 4). We found that vaccination alone taking 150 days to achieve target coverage would have decreased the cases (and deaths number) by 4.5% (23.6%), 13% (52.3%) and 20.5% (62.9%) respectively in the scenario where 20%, 50% and 70% of the population gets vaccinated over 150 days in the scenario with no NPIs used except case isolation and contact tracing (Supplementary Figure B). Vaccination when used in conjunction with social distancing (Fig. 4), it makes a small difference, reducing cases (and deaths) by 1.3% (6.2%), 3.5% (14.5%) and 5.5% (19.2%) respectively for the three scenarios of 20%, 50% and 70% coverage over 150 days. Finally, when vaccination is added to social distancing and masks, it further reduces cases only minimally, as in this scenario by the time the vaccination becomes effective, masks use and social distancing have already reduced transmission effectively (Supplementary Figure C).

In the Table 1 we show number of cumulative cases and deaths for the first COVID-19 wave in NYC with all different NPIs and vaccination (in case of its earlier availability) starting from the 1st of March. In each scenario is included isolation of cases and contacts traced and quarantined.

Table 1
Results of cumulative cases and deaths in different outbreak response scenarios.

Outbreak response	Cumulative cases	Cumulative deaths
No response	3,948,403	41,293
Vaccination alone (50 % vaccinated in 150 days)	3,424,822	19,871
Vaccination + Social distancing	236,245	927
Masks alone	7,194	58
Masks + Social distancing	4,419	43
Vaccination + masks + social distancing	4,405	42

4. Discussion

Whilst vaccines with reasonable duration of efficacy are the only feasible long-term exit strategy from the pandemic, for vaccination to have early impact on epidemic growth, uptake must be rapid and reach high levels coverage in a short period of time [28]. Israel had a rapid vaccination program, and much of the United States followed, with almost 66% of the New York State population fully vaccinated eight months later, by August 2021[29]. The CDC dropped mask mandates for fully vaccinated people in May 2021, but recommended them again in August after resurgence of COVID-19 caused by the Delta variant. With some vaccine escape, waning of vaccine induced immunity and a much higher R0, masks and other restrictions will likely need to be used for some time [30], while achieving herd immunity will be very challenging without vaccination of children and boosters, both of which have since occurred in the US.

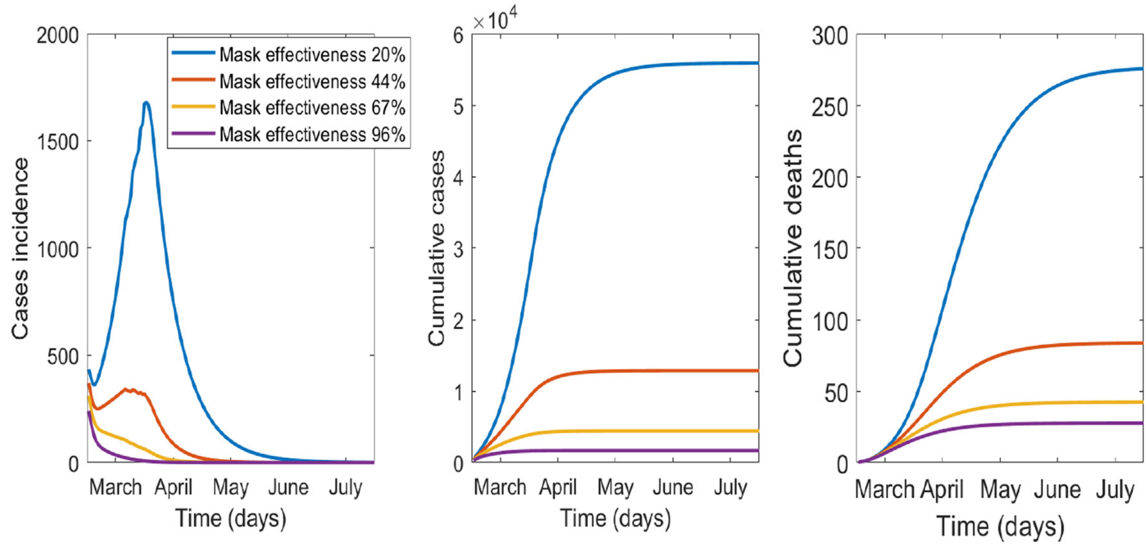

Fig. 2. Sensitivity analysis on effectiveness of masks varying from 20% to 96% - impact on incidence of cases, cumulative cases and deaths, in the base case scenario (50% wearing a mask from March 1st).

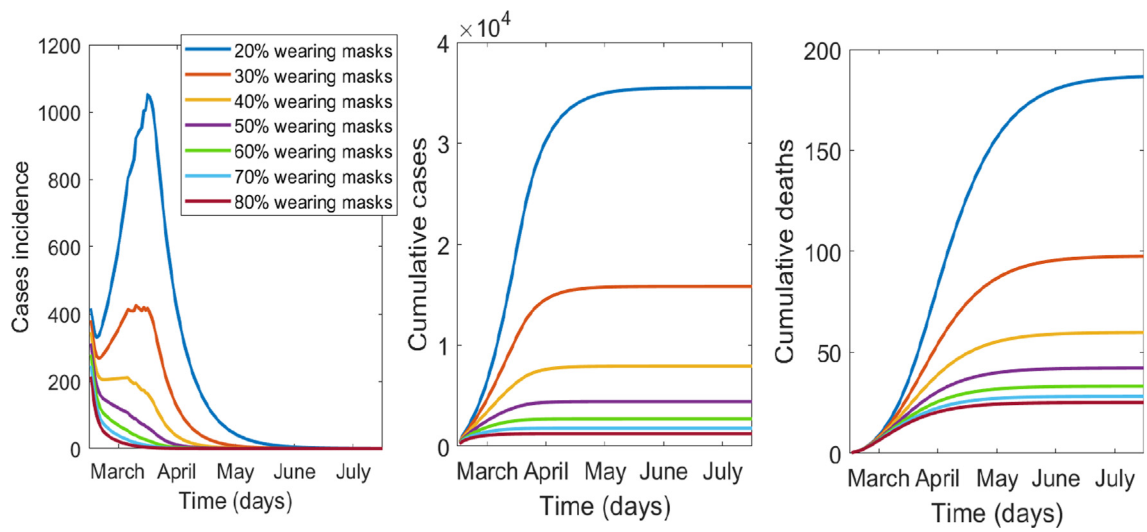

Fig. 3. Sensitivity analysis on percentage of people wearing masks varying from 20% to 80%, on incidence of cases, cumulative cases and deaths, in the base case scenario (mask efficacy 67%), from March 1st, with social distancing.

The impact of masks and physical distancing on epidemic growth is rapid, whereas a slow rise in vaccine uptake of a two-dose schedule will not have an immediate impact because of the time taken to reach full immunity. During a gradual roll-out of vaccines, the impact of vaccination will be too slow to be seen at a population level. We incorporated the time between first and second dose being three weeks, based on the mRNA vaccines being used in the US.

We showed that for the D614G variant, early, pre-emptive universal medical face mask use can reduce the risk of a severe epidemic and will still be required with a gradual roll-out of vaccination in the medium term. Facemasks are effective for control of COVID-19 at levels of 50% or greater uptake if medical grade masks or high-quality cloth masks are used, however lower uptake and effectiveness in the range of 20–44%, still reduces the epidemic burden. We evaluated a range of effectiveness estimates of masks to reflect the choices consumers may avail themselves of. It has been shown that a 12-layered cloth mask may be as effective as a medical mask, and a respirator even more effective [4]. A global shortage of masks and respirators have resulted in agencies such as the US Centers for Disease Control (CDC) recommending cloth masks [31]. A pre COVID 19 randomized controlled clinical trial (RCT) showed that two-layered cotton cloth masks are not protective for health workers against common respiratory viruses, [19] but this is likely due to inadequate washing of the masks [32]. In addition, a well-designed cloth mask of good quality with many layers and good fit may provide reasonable effectiveness [20].

Vaccination programs in the US started with priority groups such as health workers and older adults. However, transmission is highest in younger people, who are also the most mobile with the highest contact rates and higher rates of mild or asymptomatic infection, making masks even more important in this age group [18]. One study suggests there is a higher shedding risk in people with asymptomatic and mild infection compared to clinically severe disease [33]. Therefore, the use of face masks, together with social distancing and other NPIs, are important disease control strategies for reducing transmission while vaccination rates are low, and some age groups remain unvaccinated. This is particularly

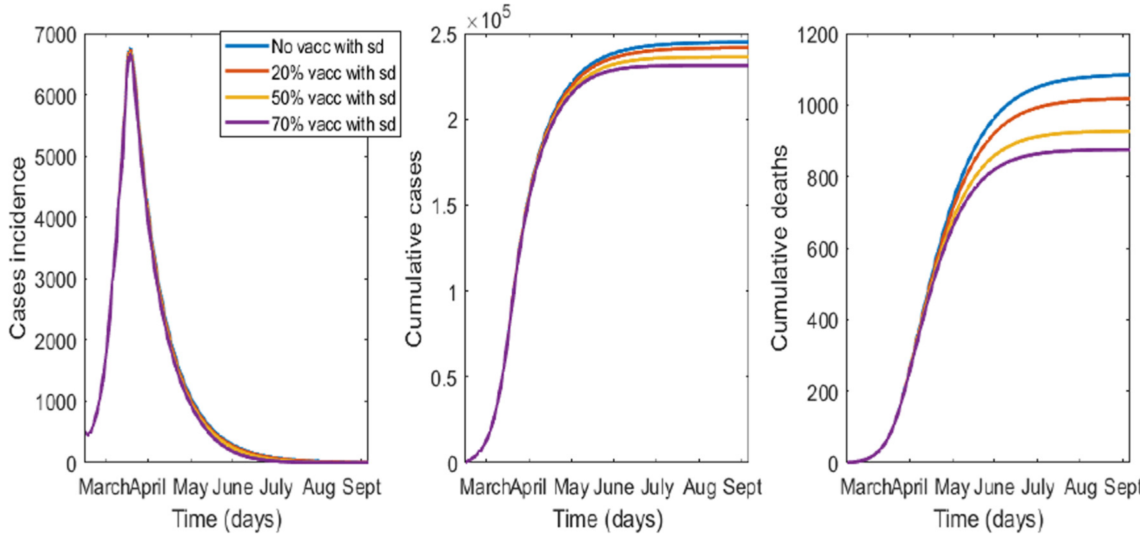

Fig. 4. Impact of vaccination with social distancing, with no mask use, on incidence of cases, cumulative cases and deaths, with vaccination over 150 days (0%, 20%, 50% and 70%).

important with the lack of clinical trial data on vaccines for children under 12 years, which means children will be the last group to be vaccinated.

The limitations of this study are that we did not model superspreading, which is difficult to predict [34]. Some outbreaks have involved apparent superspreading with very high attack rates and may indicate greater airborne spread [35]. We averaged transmission across the modelled population, so the overall population outcomes are likely still valid. The model used estimates of mask effectiveness from the best available observational data, but there are no clinical effectiveness data for the wide range of different cloth mask designs, nor for improper use of masks or for double masking, which has recently been recommended. We dealt with this with a wide range of estimates in a sensitivity analysis. We only considered medium term scenarios with gradual increases in vaccine uptake, and did not look at rapid, high coverage. In the long term, herd immunity through vaccination may be possible if high enough coverage is achieved with vaccines that have high efficacy against all infection [28]. However, data on efficacy against all infection with boosters or Delta-matched vaccines is not yet available, and duration of immunity is unknown. Out results are similar to other studies using different modelling approaches [36]. A strength of the study is that our model fitted well to observed data in the first wave, providing validation of the model.

In conclusion, universal mask use is an effective and low risk strategy for disease control, and should be used early, alongside other NPIs as vaccination programs roll out [37,38]. When vaccine roll out is slow and in cities experiencing local transmission of COVID-19, masks are necessary to mitigate transmission until vaccine coverage is high and complete. The emergence of the Delta variant as well as waning of vaccine efficacy have required reinstating of mask recommendations. The ongoing need for NPIs is unknown and will depend on future vaccine schedules, long-term duration of vaccine efficacy, vaccination of children, vaccine uptake, use of boosters and the emergence of vaccine escape variants.

CRediT authorship contribution statement

C. Raina MacIntyre: Conception, Methodology, Writing – review & editing. **Valentina Costantino:** Methodology, Writing – review & editing. **Arjun Chanmugam:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval and consent to participate

This study is a modelling study which uses open access published data and does not contain any individual or identifying data. As such, no ethics approval was required.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2021.08.102.

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