Modeling the Impact of School Reopening on SARS-CoV-2 Transmission

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Abstract

Background

Mathematical modeling studies have suggested that pre-emptive school closures alone have little overall impact on SARS-CoV-2 transmission, but reopening schools in the background of community contact reduction presents a unique scenario that has not been fully assessed.

Methods

Therefore, we adapted a previously published SIR (susceptible-infectious-recovered) model using contact information from Shanghai to model school reopening under various conditions.

Results

We find that reopening schools for all children would maintain effective $R_0 < 1$ up to a baseline $R_0$ of 3.3 provided that daily contacts among children 10–19 years are reduced to 33% of baseline. This finding was robust to various estimates of susceptibility to infection in children relative to adults (up to 50%) and to estimates of various levels of concomitant reopening in the rest of the community, with minimal change in transmission when contact frequency in the rest of the community was returned up to 40% of baseline.

Conclusions

These results suggest that schools can reopen safely with proper precautions during conditions of extreme contact reduction and during conditions of reasonable levels of reopening in the rest of the community.

Background

The COVID-19 pandemic presents an unprecedented global public health challenge. A crucial issue that remains unresolved is the role of children in SARS-CoV-2 transmission and the impact of schools on epidemic spread. Available evidence suggest that children, particularly children < 10 years, are less susceptible to SARS-CoV-2 infection [1–4] and rarely transmit infection to adults or schoolmates [5]. However, guided chiefly by prior models of pandemic influenza, which is much more transmissible among children, school closures have been a nearly universal component of pandemic response [6]. Some mathematical modeling studies suggest that school closures alone have limited effects on SARS-CoV-2 transmission [1, 7], which has been interpreted by some to suggest that little harm can follow from school reopening. Reopening schools in the setting of strict community-wide physical distancing, however,
reintroduces a mode of disease transmission that is far less redundant than typical community social networks, and therefore possibly much more important.

**Methods**

To assess the effect of school reopening on SARS-CoV-2 transmission, we adapted the SIR (susceptible-infectious-recovered) model of SARS-CoV-2 transmission as developed and reported by Zhang et al. using contact data from Shanghai [1] to examine transmission dynamics under various school reopening conditions. The original model used empirical contact matrices among a population stratified by age and observed during both baseline and pandemic “lockdown” periods to guide SIR dynamics under assumption of heterogeneous susceptibility, such that children are less susceptible (roughly 34%) to SARS-CoV-2 infection than adults. We modified the model in simple ways. First, we combined the observed “lockdown” contact matrix with different weighted blocks of the baseline contact matrix to mimic different scenarios for school reopening and background interventions. For example, since the model stratifies the population in bins of 5 years, we can model school reopening for children < 10 years by using baseline values for the 2 × 2 block of the contact matrix corresponding to interactions between children 0–4 years with one another, between children 0–4 years with those 5–9 years, between children 5–9 years with those 0–4 years, and between children 5–9 years with one other. Other values can also be weighted to a fraction of the true baseline value to mimic partial reopening or intervention conditions. Second, we relaxed assumptions of heterogeneous susceptibility across age groups. Mainly, Zhang et al. estimated a relative susceptibility of roughly 34% for children < 15 y.o. compared to adults. We relaxed this assumption by increasing the relative susceptibility of children to different values (34%, 40%, 45%, 50%, 60%) while leaving older populations unchanged.

Our adapted model is presented and freely available at https://github.com/LaurentHebert/school-reopening.

**Results**

When no measures are taken to reduce $R_0$, baseline $R_0$ and effective $R_0$ are identical (Fig. 1, dashed black line). School closure alone has minimal effect (Fig. 1, orange line) because disease continues to spread via alternate social contacts in the community. Full “lockdown,” in contrast, has a major effect (Fig. 1, solid green line) because it severs most social contacts. Therefore, to simulate the effect of school reopening against this background, we reincorporated baseline contact patterns for children (aged 0–19) into the full “lockdown” model, using the same underlying assumptions for contact patterns and reduced susceptibility to infection by age as reported for Shanghai during outbreak conditions [1]. This shows a dramatic effect (Fig. 1, solid blue line): reopening schools without measures to reduce daily contacts would return transmission levels virtually to baseline despite strict physical distancing in the rest of the community, and thus would be highly inadvisable. The fact that school closures alone have little impact does not imply that school reopening during a “lockdown” will similarly have little impact.
We then assessed various conditions for school reopening to estimate impacts on effective $R_0$, including implementation of measures to reduce contacts among children. We find that reopening schools for children < 10 years, even without reduction in daily contacts, is predicted to maintain effective $R_0 < 1$ (and suppress virus transmission) up to a baseline $R_0$ of ~ 4.5 (Fig. 1, dashed blue line). The addition of school reopening with reduction in daily contacts among children 10–19 to 33% of baseline is predicted to keep effective $R_0 < 1$ up to a baseline $R_0$ of ~ 3.3 (Fig. 1, interrupted blue line). These results suggest that interventions to reduce the number of contacts at school, with an emphasis on children 10–19 years, is a potentially viable approach to school reopening even during periods of significant baseline community transmission of SARS-CoV-2 while strict contact suppression is maintained in the rest of the community. We find that reopening schools to children < 10 would have the least impact on disease transmission, even when we assumed that these children would be unable to adhere to interventions to reduce their effective number of daily contacts.

The feasibility of these interventions rely in part on the limited contacts between children and older populations but also on estimates of their lower susceptibility to SARS-CoV-2. Given that the model developed by Zhang et al. estimated a relative susceptibility of roughly 34% for children under 15 years compared to adults, we next looked at the robustness of our results to varying estimates of susceptibility (Fig. 2). We increased the relative susceptibility of children up to 60%, and found that our suggested reopening model remained quite robust to changes in virus susceptibility among children. In particular, the idea of full reopening for children under 10 years with contact reduction for children 10–19 years remained feasible up to a baseline $R_0$ of ~ 3, even when relative susceptibility of children was estimated at 50% that of adults (itself a 50% increase compared to the original model estimates).

Recognizing however that school reopenings would generally occur alongside other relaxations on community restrictions, we then looked at the robustness of this model in the context of gradual increases in the frequency of contacts for the rest of the community (Fig. 3). We find that return of contact frequency to 20% (Fig. 3, dotted blue line) and 30% (Fig. 3, dashed blue line) of pre-pandemic baseline among all other community members has virtually no additional impact on transmission. At 40% of baseline, effective $R_0$ remains suppressed < 1 up to a baseline $R_0$ of ~ 2.5, and at 60% of baseline, effective $R_0$ remains suppressed < 1 up to a baseline $R_0$ of slightly less than 2. These results suggest that even with relaxations in contact reduction measures in the rest of the community, school reopening remains feasible with reasonable measures to reduce contact frequency in the school setting.

**Discussion**

In an SIR model of SARS-CoV-2 transmission utilizing contact patterns obtained from Shanghai [1], we find that school reopening can proceed safely and maintain effective $R_0 < 1$ under a wide range of both baseline $R_0$ levels and estimates of susceptibility to infection in children, provided that appropriate measures are taken in the school and community settings to reduce the number of daily contacts among both children and school and community members. We find that younger children < 10 have the least
impact on disease transmission, and greatest priority in the school setting should focus on children 10–19 years of age. In this model, contact suppression was calculated as a percentage of baseline, pre-pandemic contact patterns. Reducing the number of effective daily contacts could occur via complete removal of a specific proportion of typical contacts, or by use of other non-pharmaceutical interventions such as facial coverings and physical distancing, which might proportionally reduce risk of transmission during any individual encounter,[8] but which were not included as discrete variables in this model. Additional strategies for reducing the frequency of close contacts within school settings have been proposed by the World Health Organization and the Centers for Disease Control and Prevention, such as eliminating large group activities, reducing student movement, and allowing for a mixture of in-class and remote learning to reduce classroom size and density[9, 10]. Scheduled hand hygiene and frequent disinfection of common surfaces would also reduce potential transmission.

There are several limitations to these findings. Notably, the baseline and outbreak contact patterns utilized in this model, which used data from Shanghai, may not be generalizable to all settings due to underlying differences in social contact networks and the achievable magnitude of contact suppression during mandated physical distancing. This model would not apply to college or university settings (based on an upper age limit of 19), nor to boarding schools. Based on a preponderance of current evidence, this model assumes that children are less susceptible to infection; since school closures were typically implemented along with community physical distancing mandates[6], this observation could be an artifact of limiting child contacts to within households early in the pandemic rather than a true biological difference. If children prove to be equally susceptible to infection, this model may significantly underestimate the impact of school reopening, although this may be mitigated by the effect of universal masking and increased physical distancing within the school environment. Therefore, school reopening would require flexibility to rapidly adapt to changing local conditions, along with capacity for aggressive testing and contact tracing of infected children and their families: because infected children generally have mild symptoms[11], school-associated outbreaks might present with clusters of illness in parents or household contacts. The effects of infection in some children may also be more severe than previously appreciated, due to development in a small minority of infected children of a novel and serious multisystem inflammatory syndrome associated with COVID-19 (MIS-C) that is still being characterized[12].

Finally, we looked at the impact of school reopenings without accounting for possible secondary changes in behavior among parents and other contacts as a result. It is possible that school reopenings could lead to behavioral changes that would increase transmission risks in the community outside the school setting (for example, by relaxing attitudes or concerns regarding physical distancing or maximum group sizes). This might have two major unintended consequences, both detrimental. First, it could lead to increased viral transmission overall and loss of epidemic control. Second, this increase in transmission might erroneously be attributed to school reopenings themselves, prompting re-closures (and all associated educational, economic, and societal harms), which would then be minimally effective at curtailing further transmission. Therefore, school reopenings necessitate careful public health messaging
to reinforce the need for ongoing community-wide measures and to place the potential impact of school reopenings into proper context, to limit viral transmission.

**Conclusions**

Schools can be reopened safely in the setting of ongoing SARS-CoV-2 community transmission, if appropriate and reasonable precautions are maintained to reduce the background rate of daily contacts in the community along with reducing daily social contacts among children in the school setting. The impacts of prolonged school closure on child health, development, and education may be profound, and for most children and families, particularly younger children with working parents, remote learning has been an alarmingly poor substitute for the classroom [13–15]. We argue for a paradigm that prioritizes open schools, rather than viewing school closures as necessary adjuncts to other community-level interventions [6, 16], and that approaches based on influenza suppression may be ill-suited for this pandemic given the clear differences between influenza and SARS-CoV-2, particularly regarding their effects on children. Strategies for safely reopening schools can be guided by mathematical modeling approaches, particularly wherever contact data are available to generate local estimates to inform public health policy.

**Abbreviations**

SIR
susceptible-infectious-recovered

$R_0$
basic reproduction number

**Declarations**

**Ethics approval and consent to participate:** Not applicable

**Consent for publication:** Not applicable

**Availability of data and materials:** All data are freely available at https://github.com/LaurentHebert/school-reopening.

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JPH: Methodology

SN: Methodology
Acknowledgments: None

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Figures
Figure 1

Effects of school reopening during community “lockdown.” Effective R0 as a function of baseline R0 under various conditions are shown. Dashed black line: Baseline, represents all contact patterns pre-pandemic. Solid orange line: School closure alone, represents community pre-pandemic contact patterns but with contacts among children 0-19 removed to simulate full school closure. Solid green line: Full “lockdown,” represents full contact suppression during pandemic conditions. Solid blue line: Full school reopening, represents full “lockdown” conditions but with re-incorporation of all contacts among children 0-19 according to baseline contact patterns to simulate return to full school attendance. Interrupted blue line: Reopen <10 y.o., partial above, simulates the effect of re-incorporating full contact patterns for
children 0-9 with reduction in contacts in children 10-19 to 33% of baseline. Dashed blue line: Reopen <10y.o. only, simulates the effect of re-incorporating baseline contact patterns for children 0-9 only.

Figure 2

Effects of school reopening based on differing rates of susceptibility to SARS-CoV-2 infection in children relative to adults. Effective R0 as a function of baseline R0 under various estimates of susceptibility to SARS-CoV-2 infection in children <15 years are shown. Dashed black line: Baseline, represents all contact patterns pre-pandemic. Solid black line: Reopen <10 y.o., partial above, simulates the effect of re-incorporating full contact patterns for children 0-9 with reduction in contacts in children 10-19 to 33% of baseline. Starting from this condition, blue lines represent a range of estimates of susceptibility to SARS-
CoV-2 infection in children relative to adults: 40% (dotted blue line), 45% (dashed blue line), 50% (interrupted blue line), and 60% (solid blue line).

Figure 3

Effects of school reopening along with community reopening. Effective R0 as a function of baseline R0 under various conditions are shown. Dashed black line: Baseline, represents all contact patterns pre-pandemic. Solid black line: Reopen <10 y.o., partial above, simulates the effect of re-incorporating full contact patterns for children 0-9 with reduction in contacts in children 10-19 to 33% of baseline. Starting from this condition, blue lines represent the effects of restoration of contact frequency in the rest of the community (i.e. community reopening) to 20% of baseline (dotted blue line), 30% of baseline (dashed blue line), 40% of baseline (interrupted blue line), or 60% of baseline (solid blue line).