Estimating the impact of reopening schools on the reproduction number of SARS-CoV-2 in England, using weekly contact survey data

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Abstract

We measured social contacts when schools were either open or closed, amongst other restrictions. We combined these data with estimates of the susceptibility and infectiousness of children compared with adults to estimate the impact of reopening schools on the reproduction number. Our results suggest that reopening all schools could increase R from an assumed baseline of 0.8 to between 1.0 and 1.5, or to between 0.9 and 1.2 reopening primary or secondary schools alone.

Keywords: School closure, SARS-CoV-2, COVID-19, Social Contacts, Reproduction Number, CoMix

Lockdowns and school closures

On the 4th of January 2021, a third national lockdown in England was announced to curb transmission of SARS-CoV-2 (1). This involved the closure of schools, a measure taken during the first lockdown (March 2020) but not during the previous lockdown in November 2020. Children's contacts increase when schools are open, presenting opportunities for increased infectious disease transmission (2). However, the impact of school closure on the transmission of SARS-CoV-2 is unclear. We combined social-contact data collected throughout the period by the CoMix survey (3) with estimates of age-stratified susceptibility and infectiousness (4–6), to estimate the impact of opening schools on the reproduction number in England.

Age-dependent transmission risk

Susceptibility and infectiousness of children likely differs from adults, due to variation in prior exposure with SARS-CoV-2 and other factors unrelated to history of infection. We consider five age-dependent susceptibility and infectiousness profiles (Table S1): i, equal susceptibility and infectiousness in all age groups; ii, age-stratified susceptibility and infectiousness as estimated by Davies et al (4); iii, 50% susceptibility in children relative to adults but equal infectiousness, based on analyses of household transmission patterns from the Office for National Statistics (ONS) Community Infection Study (5); iv, 64% susceptibility in children relative to adults, based on a meta-analysis of results presented in a systematic review of susceptibility from Viner et al and assumed equal infectiousness (6); and v. 31% susceptibility in children relative to adults, quantified by comparing reproduction numbers estimated from CoMix data and using case data.

We also established independent estimates of susceptibility and infectiousness in children relative to adults. We compared estimates of *R* using CoMix contact data with estimates of the time-varying reproduction number in England calculated using case data (7) (Figure 1). To capture the change in contact rates as schools returned in September 2020, we used maximum likelihood to fit relative susceptibility in children, over data from 27th July to 10th October, while keeping infectiousness equal across age-groups. This resulted in 44% susceptibility (Figure 1, A & C), consistent with profiles ii and iii. We also fitted from the 10th June to 10th October, 2020, giving 31% susceptibility (Figure 1, B & D), near the lower range of ONS and Davies et al estimates. We chose to apply this as the fifth susceptibility profile to represent this lower bound (Table S1) and present fits to other date ranges in the supplementary material (Fig. S4).

Evaluation of the impact of reopening schools

To demonstrate the potential impact of reopening schools, we estimated the relative increase in reproduction number (*R*) by calculating the ratio of dominant eigenvalues of the effective contact matrix associated with the respective reopening scenario and from the current lockdown period. Uncertainty for these ratios was calculated using bootstrap samples of the contact data (8). We also calculated how *R* varies from baseline values between 0.7 and 1.0, from official UK estimates of the reproduction number from (9).

We created contact matrices using CoMix data collected during the second lockdown, (5th November to 2nd December 2020) to represent contacts during a lockdown with schools open. We used data from 5th to 18th of January 2021 for contacts during a lockdown with schools closed (Figure S1). We constructed further synthetic contact matrices representing opening primary or secondary schools by replacing the contacts of 5-10 year-olds (primary) and 11-17 year-olds (secondary) in the ‘schools open’ contact matrix (second lockdown), with those from the ‘schools closed’ contact matrix (third lockdown) (Figure S2).

Incorporating estimates of differential susceptibility and infectiousness of children compared with adults (profiles ii - v), full school reopening increased *R* by a factor of between 1.3 and 1.9 times the baseline value across the four profiles used (including 90% CI range) (Figure 2, Table 1). This would result in an increase of *R* from 0.8 to above 1.0 for these four profiles. Partial school reopening resulted in smaller increases in *R* from 0.8 to between 0.9 and 1.2.

Table 1 Expected resultant *R* if schools were reopened for different baseline values of *R* reported as median (95% CI)

		Baseline *R*			
Susceptibility/ Infectiousness	**Attendance**	**0.7**	**0.8**	**0.9**	**1.0 (Scale factor)**
1. Equal	Both	1.6 (1.5 - 1.6)	1.8 (1.7 - 1.9)	2.0 (1.9 - 2.1)	2.2 (2.1 - 2.3)
	Primary	1.1 (1.0 - 1.1)	1.2 (1.2 - 1.3)	1.4 (1.3 - 1.5)	1.5 (1.4 - 1.6)
	Secondary	1.1 (1.0 - 1.2)	1.3 (1.2 - 1.3)	1.4 (1.3 - 1.5)	1.6 (1.5 - 1.7)
2. Davies et al	Both	1.1 (1.0 - 1.1)	1.2 (1.1 - 1.3)	1.4 (1.3 - 1.4)	1.5 (1.4 - 1.6)
	Primary	0.9 (0.8 - 0.9)	1.0 (0.9 - 1.0)	1.1 (1.1 - 1.2)	1.2 (1.2 - 1.3)
	Secondary	0.9 (0.8 - 0.9)	1.0 (1.0 - 1.1)	1.1 (1.1 - 1.2)	1.3 (1.2 - 1.3)
3. ONS	Both	1.1 (1.1 - 1.2)	1.3 (1.2 - 1.3)	1.4 (1.4 - 1.5)	1.6 (1.5 - 1.7)
	Primary	0.9 (0.8 - 0.9)	1.0 (1.0 - 1.1)	1.1 (1.1 - 1.2)	1.3 (1.2 - 1.3)
	Secondary	0.9 (0.9 - 1.0)	1.0 (1.0 - 1.1)	1.2 (1.1 - 1.2)	1.3 (1.3 - 1.4)
4. Viner et al	Both	1.3 (1.2 - 1.3)	1.4 (1.4 - 1.5)	1.6 (1.5 - 1.7)	1.8 (1.7 - 1.9)
	Primary	0.9 (0.9 - 1.0)	1.1 (1.0 - 1.1)	1.2 (1.1 - 1.3)	1.3 (1.3 - 1.4)
	Secondary	1.0 (0.9 - 1.0)	1.1 (1.1 - 1.2)	1.2 (1.2 - 1.3)	1.4 (1.3 - 1.4)
5. CoMix fit	Both	0.9 (0.9 - 1.0)	1.1 (1.0 - 1.1)	1.2 (1.2 - 1.3)	1.4 (1.3 - 1.4)
	Primary	0.8 (0.8 - 0.9)	0.9 (0.9 - 1.0)	1.1 (1.0 - 1.1)	1.2 (1.1 - 1.2)
	Secondary	0.8 (0.8 - 0.9)	1.0 (0.9 - 1.0)	1.1 (1.0 - 1.1)	1.2 (1.2 - 1.3)

Assuming equal infectiousness and susceptibility between all age groups, reopening schools resulted in more substantial relative changes in *R*. Full school reopening increased *R* by a factor of between 2.1 and 2.3 (Figure 2, Table 1), resulting in an increase of *R* to roughly 1.7-1.9 from a baseline of 0.8 (Table 1). Partial re-opening increased *R* from 0.8 to 1.2-1.3 (Figure 1). We included these estimates for completeness but stress that assuming that children are equally infectious and susceptible as adults is not compatible with results from previous studies or our own estimates (Figure 1).

Strengths and Limitations

This study uses social contact data collected prospectively from a large represented panel of individuals in the UK during two periods of lockdowns, separated by a period of one month, that differed solely in whether schools were open or not. That is, it makes use of a natural experiment. The study does, however, have limitations. Contacts in different settings likely contribute differently to transmission, but we assumed all contacts make equal contributions to transmission, as these differences are not well quantified in the context of control measures. The age-stratified susceptibility profile is likely to change over time as natural immunity is acquired in the population. The profiles we used each reflect a single point in time. Changes in the relative immunity in children would alter the results. We assume adult contacts revert to those observed when all schools were open, which is conservative, in reality, in partial reopening scenarios, adult contacts may not fully return to the same levels. Furthermore, there may also be differences in adherence to restrictions between the two lockdowns, unrelated to school closure. The proportion of children in school varied over time due to exclusion-based control measures during the autumn, though the proportion attending school remained high during the November lockdown (Figure S3). Contacts of children are reported by parents, which may impact their reliability, particularly in school, where parents are unlikely to witness students' behaviour.

Further considerations for opening schools

There are other factors that reopening schools may introduce, such as the potential for children's contact at school to provide routes of transmission between households, facilitating long chains of transmission that would be otherwise impossible(10). We are not able to capture these network effects in this analysis, however they may play an important role in the change in epidemiology between school closure and reopening.

Second, there is evidence for lower prevalence in primary school than secondary schools (11). Our framework has not captured these differences suggesting there may be additional factors that reduce the impact of reopening primary schools relative to secondary schools.

Furthermore, additional management strategies such as mass testing of school children, may serve to reduce the risk that a contact in a school results in infection beyond those implemented last year.

Finally, with the recent emergence of new variants, particularly B.1.1.7(12), the baseline *R* will depend on proportions of these variants as well as contact patterns. Furthermore, these proportions are likely to change, potentially altering the implications of reopening schools.

Conclusion

Our results suggest reopening schools is likely to increase *R* close to or above 1.0, which would stop the decrease in cases observed in recent weeks. However, more precise estimates rely heavily on the baseline values of *R* and the profiles of susceptibility, generally assuming lower susceptibility and no greater infectiousness in children relative to adults.

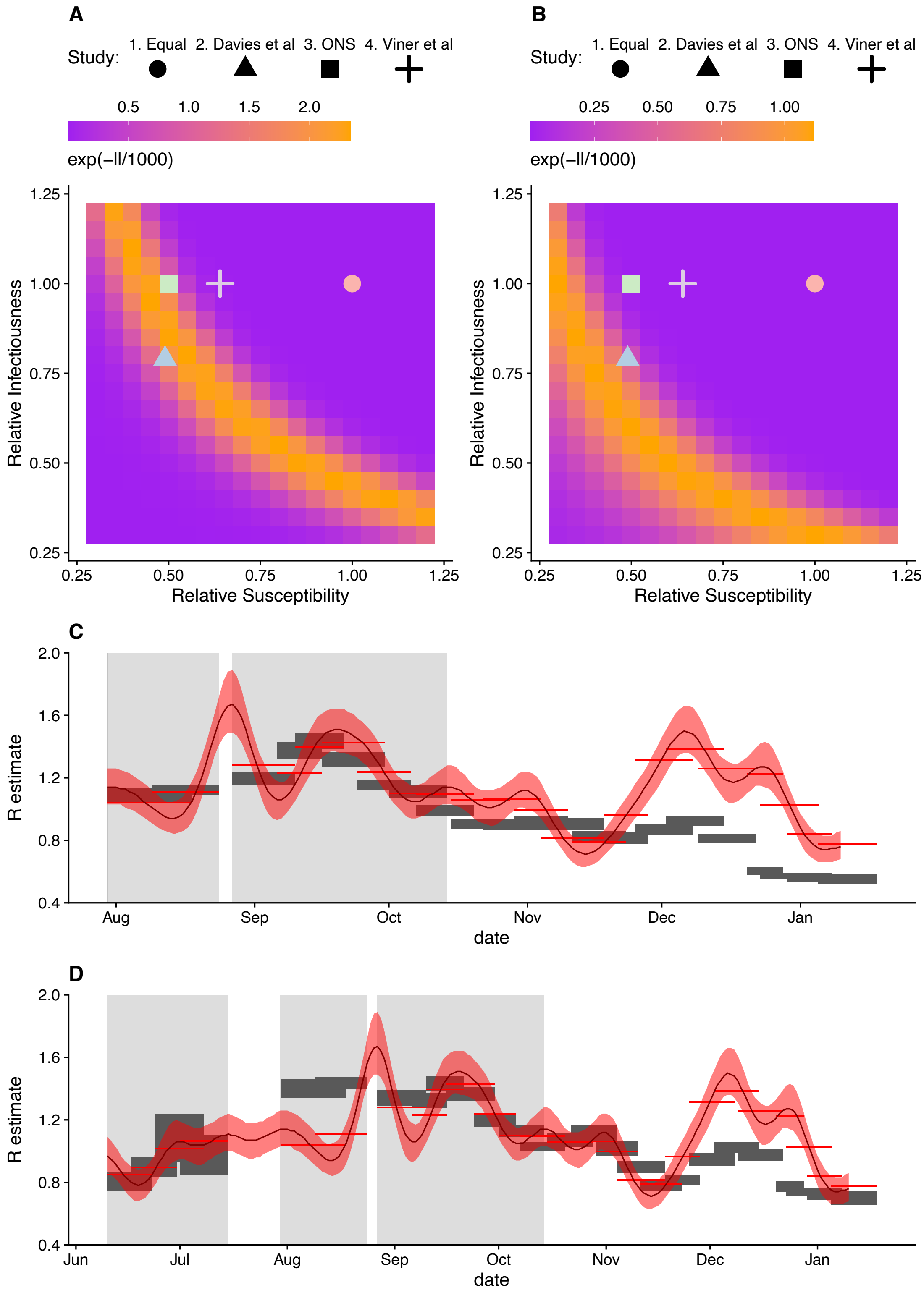

***Figure 1: R estimates using CoMix data fit to time-varying reproduction number estimates based on the time series of cases** (7). Transformed likelihood for different combinations of relative susceptibility and infectiousness based on data from **A)** August to October and **B)** June to October and the corresponding R estimates in **C)** and **D)** respectively. 90% CI of the estimates are shown by Grey rectangles for CoMix and the red ribbon for the time-varying reproduction number estimates from case data, red bars show their mean for the CoMix survey periods. Grey shaded areas indicate fitted periods.*

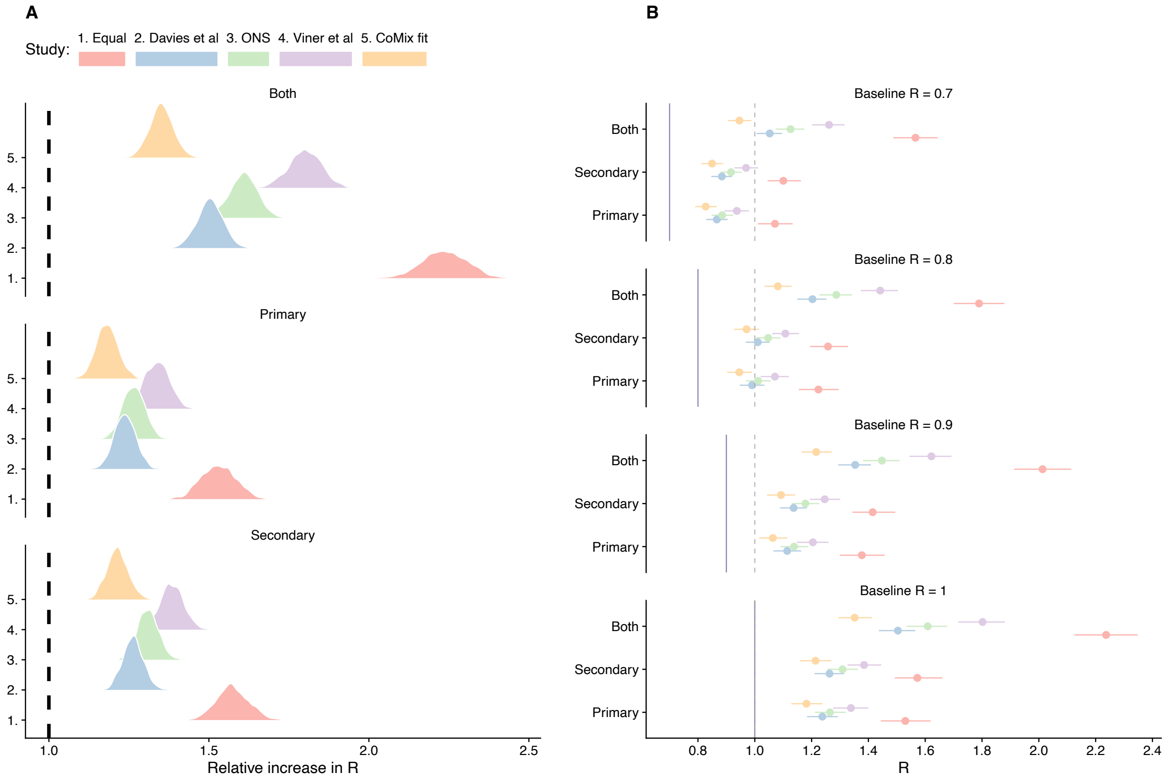

Figure 2: The impact of reopening schools on the reproduction number. A) *the relative increase in R (the ratio of dominant eigenvalues between contact matrices for each reopening scenario and that for current contact patterns) under different estimates of the age profile of susceptibility and infectiousness.* ***B)*** *The estimated R after reopening schools (points, 90% CI bars) from baseline R of 0.7, 0.8, 0.9 and 1.0 (vertical line). Dashed vertical lines show R = 1.0.*

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Ethics approval and consent to participate

Participation in this opt-in study was voluntary, and all analyses were carried out on anonymised data. The study and method of informed consent was approved by the ethics committee of the London School of Hygiene & Tropical Medicine Reference number 21795.

Code and data availability statement

Although it is not possible to share the contact survey data used to generate the contact matrices used in this analysis. The analysis code and contact matrices used are available in an online repository here: https://github.com/jdmunday/CoMix_schools_reopening

Authors contributions

JDM, CIJ, WJE conceived of and planned the analysis; JDM and CIJ performed the main analysis with input from WEJ and SF; SF provided estimates of time-varying reproduction number; CIJ, KvZ, and WEJ designed the CoMix contact survey, CIJ, AG, KW, and KvZ cleaned and managed the contact survey data; All authors wrote and reviewed the manuscript. The CMMID COVID-19 Working Group provided discussion and comments.

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Competing interests

None

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