The effect of school opening or closure on social contacts in England from the CoMix social contact survey
Report for survey week 43b

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Data up to 18th of January 2021

Summary

- We used contact data collected during the second and third national lockdown to construct contact matrices that estimate the changes in contacts and transmission for opening primary and secondary schools during a national lockdown.
- We estimated the impact of school reopening on the reproduction number by taking the ratio of the dominant eigenvalues under various assumptions of age-dependent susceptibility and infectiousness based on estimates in the literature.
- We found that reopening all schools increased R_0 by a factor of between 1.3 and 1.9 with estimates of reduced transmissibility in children incorporated, raising to 2.2 - 2.5 if the infectiousness and susceptibility of children was assumed to be equal to adults.
- Opening only primary or only secondary schools resulted in an increase by a factor of between 1.1 and 1.4 with reduced infectiousness and susceptibility in children incorporated and 1.5 - 1.8 if infectiousness and susceptibility was assumed equal to adults.
- The results suggest that reopening schools could increase R_0 from a baseline of 0.8 to between 0.9 and 1.2 with partial reopening and between 1.1 and 1.5 for full reopening incorporating estimates of reduced infectiousness and susceptibility in children.

Main

On the 4th of January 2021 the UK government announced a third national lockdown in England to curb transmission of SARS-CoV-2[1]. This involved the closing of schools, a measure which was not taken during the previous lockdown in November 2020. It is established that children's contacts increase when schools are open[2] (Figure S1), however, the relative impact of school closure on the overall transmission for SARS-CoV-2 is unclear. We combined social contact data collected in a large weekly survey[3] and estimates of age stratified susceptibility and infectiousness[4–6], to estimate the relative impact of opening schools on the basic reproduction number in England.

We used social contact data collected during the second national lockdown from the 5th November to 2nd December 2020 as a baseline for social contacts during a lockdown with schools open. We used contact data collected from the 5th to the 18th of January 2021 to represent social contacts during a lockdown with schools closed. We constructed a further contact matrix representing primary schools being open by replacing the contacts of 5-10

year-olds in the 'schools open' contact matrix (second lockdown), with those from the 'schools closed' contact matrix (third lockdown) (Figure S2). This was repeated for 11-17 year-olds to create a matrix for opening secondary schools.

We used these matrices to estimate the relative increase in R_0 upon school reopening under five susceptibility and infectiousness profiles: 1, susceptibility and infectiousness are equal in all age groups; 2, based on the relative susceptibility and infectiousness of children compared to adults as estimated by Davies et al [4]; 3, children's (0-17 year olds) susceptibility being half that of adults, but equal infectiousness; 4, susceptibility of 0-17 being 40% that of adults and infectiousness 110% that of adults; and 5, susceptibility of 0-17 year olds being 64% of that of adults with equal infectiousness across all age groups, based on a random effect meta-analysis model applied to results presented in a systematic review of relative susceptibility in children and adults from Viner et al[6] (Figure S3, S4). Scenarios 3 and 4 are based on analyses of household transmission patterns from the Office for National Statistics (ONS) Community Infection Study[5], (Table S1). In addition, to demonstrate the potential impact of reopening schools according to our estimates, we show how R_0 would vary from baseline values of 0.8, 1.0 and 1.2.

Incorporating estimates of differential susceptibility and infectiousness of children compared with adults, school opening increases R_0 by a factor of between 1.3 and 1.9 for full school opening across the four profiles used (Table S2). This would result in an increase of R_0 from 0.8 to above 1.0, and from 1.2 to between 1.6 to 2.3 for the four profiles used. Partial reopening resulted in lower impact increasing R_0 but would still increase from 0.8 to 0.9 - 1.2 or or from 1.2 to 1.3 - 1.7. Slightly different values are seen for the four different profiles of susceptibility and infectiousness but the values are broadly consistent.

When assuming equal infectiousness and susceptibility between all age groups, reopening schools resulted in much more substantial relative changes in R_0. Full school reopening would increase R_0 by between 2.2 and 2.5 times the baseline value (Figure 1, Table S2). This would result in an increase of R_0 to roughly 1.8 - 2.0 from a baseline value of 0.8, or between 2.7 and 3.0 from a baseline value of 1.2 (Table S3). Partial re-opening (either secondary or primary) has a more limited impact on R_0 increasing from 0.8 to 1.2 - 1.4 and from 1.2 to 1.7 - 2.1.

Our calculations suggest that reopening all schools will increase R_0 to close to 1.0, which would arrest the reduction in cases observed in recent weeks. These results rely heavily on the estimates that we used indicating generally lower susceptibility and perhaps infectiousness in children relative to adults. If this effect is ignored our results show a much higher impact on R_0.

There are some important limitations to this analysis. Contacts of 0-17 year olds are reported by parents, which may impact their reliability, particularly in school, where parents are unlikely to witness their contact behaviour. The specific age of contacts under 18 are reported as an age-band as opposed to an exact figure. However, these bands broadly follow pre-school, primary and secondary divisions. The proportion of children in school varied over time due to exclusion based control measures during the autumn. However, the proportion of children

attending school remained high during the November lockdown (Figure S5). With the recent emergence of new variants, particularly B.1.1.7[7], the baseline R_0 is likely to depend on the relative proportions of these variants as well as contact patterns in the population. These proportions are likely to change, potentially altering the implications of reopening schools.

There are also 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[8]. 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.

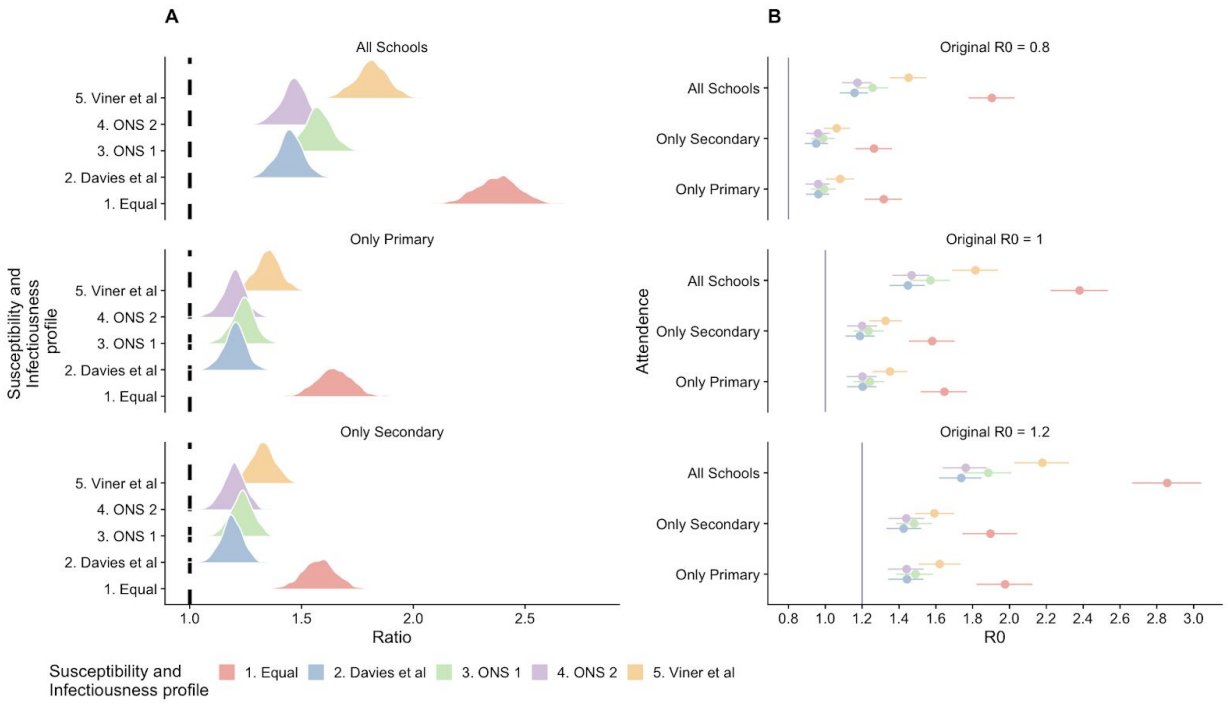

Figure 1: The impact of reopening schools on the reproduction number. A) the ratio of dominant eigenvalues between contact matrices for each reopening scenario and that for current contact patterns under different estimates of the age profile of susceptibility and infectiousness. B) The estimated R_0 after reopening schools (points, 95% CI bars) from baseline R_0 of 0.8, 1.0 and 1.2 (vertical line).

Methods detail

CoMix is a behavioural survey, launched on 24th of March 2020. The sample is broadly representative of the UK adult population. Participant's are invited to respond to the survey once every two weeks. We collect weekly data by running two alternating panels. Parents complete the survey on behalf of children (17 years old or younger). Participants record direct, face-to-face contacts made on the previous day, specifying certain characteristics for each contact including the age and sex of the contact, whether contact was physical (skin-to-skin contact), and where contact occurred (e.g. at home, work, while undertaking leisure activities, etc). Further details have been published elsewhere[3]. The contact survey is based on the POLYMOD contact survey[9].

We constructed age-stratified contact matrices for nine age-groups (0-4, 5-11, 12-17, 18-29, 30-39, 40-49, 50-59, 60-69, and 70+). For children participants and contacts, we did not have exact ages and therefore sampled from the reported age-group uniformly. We fitted a truncated negative binomial model to calculate the mean contacts between each participant and contact age-groups. To find the population normalised symmetrical contact matrix, we multiplied the columns of the matrix by the mean-normalised proportion of the UK population in each age-group.

We created the matrix for the second lockdown using data from the period of 5th November to 2nd December 2020. We created the matrix for the third lockdown using data from the period of 5th to the 18th of January 2021. Individual element absolute differences of the matrices were calculated as well as the ratio of the dominant eigenvalues comparing the third and the second lockdown (Figure S1).

We constructed a contact matrix representing primary schools being open by replacing the contacts of 5-10 year-olds in the 'schools open' contact matrix (second lockdown), with those from the 'schools closed' contact matrix (third lockdown) (Figure S2). This was repeated for 11-17 year-olds to create a matrix for opening secondary schools.

Since the basic reproduction number scales linearly with the dominant eigenvalue of a matrix of effective contact [10], the ratio of the eigenvalues of two contract matrices provides a relative change in reproduction number between the three scenarios considered.

In the case where infectiousness and susceptibility are equal in all age groups, the effective contact matrix is proportional to the contact matrix itself. Under the scenarios where we assumed infectiousness and susceptibility vary with age, we converted measured contact matrices to effective contact matrices by taking the outer product of a the estimated age stratified infectiousness profile and susceptibility profile vectors and calculating the eigenvalues of the Hadamard product of the resulting matrix and the contact matrices.

For the profiles taken from Davies et al[4], we took the mean estimates of susceptibility. This work does not report age structured infectiousness directly but rather suggests 50% infectiousness of

sub-clinical cases and reports clinical fraction by age. We used this to calculate infectiousness per age group in (Table S1).

For the profiles taken from Viner et al[6], we performed a meta-analysis using a random effects model based on the data from Figure 4 of their paper. The measures from the individual studies are presented in Figure S3 and a funnel plot of observations in Figure S4.

We calculated the proportion of children attending school on the day that contacts were measured for each survey week. Weekend observations and those when the schools were closed for holidays were removed, we present that proportion from September onwards in Figure S5.

References

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8 Munday JD, Sherratt K, Meakin S, *et al.* Implications of the school-household network structure on SARS-CoV-2 transmission under different school reopening strategies in England. *medRxiv* 2020. https://www.medrxiv.org/content/10.1101/2020.08.21.20167965v1.

9 Mossong J, Hens N, Jit M, *et al.* Social contacts and mixing patterns relevant to the spread of infectious diseases. *PLoS Med* 2008; **5**: e74.

10 Wallinga J, Teunis P, Kretzschmar M. Using data on social contacts to estimate age-specific transmission parameters for respiratory-spread infectious agents. *Am J Epidemiol* 2006; **164**: 936–44.

Supplementary tables and figures

Table S1 Susceptibility and infectiousness profiles taken from Davies et.al.[4], ONS reports and Viner et al [6]

		Susceptibility	Infectiousness	Clinical Fraction
Davies et al	0-4	0.4	0.645	0.29
	5-10	0.4	0.645	0.29
	11-17	0.4	0.605	0.21
	18-29	0.79	0.635	0.27
	30-39	0.86	0.665	0.33
	40-49	0.8	0.7	0.4
	50-59	0.82	0.745	0.49
	60-69	0.88	0.815	0.63
	70+	0.74	0.845	0.69
		Susceptibility	Infectiousness	
ONS 1	0-4	0.5	1.0	
	5-10	0.5	1.0	
	11-17	0.5	1.0	
	18-29	1.0	1.0	
	30-39	1.0	1.0	
	40-49	1.0	1.0	
	50-59	1.0	1.0	
	60-69	1.0	1.0	
	70+	1.0	1.0	
		Susceptibility	Infectiousness	
ONS 2	0-4	0.4	1.1	
	5-10	0.4	1.1	
	11-17	0.4	1.1	
	18-29	1.0	1.0	
	30-39	1.0	1.0	
	40-49	1.0	1.0	
	50-59	1.0	1.0	
	60-69	1.0	1.0	
	70+	1.0	1.0	
		Susceptibility	Infectiousness	
Viner et al	0-4	0.64	1.0	
	5-10	0.64	1.0	
	11-17	0.64	1.0	
	18-29	1.0	1.0	
	30-39	1.0	1.0	
	40-49	1.0	1.0	
	50-59	1.0	1.0	
	60-69	1.0	1.0	
	70+	1.0	1.0	

Table S2 Ratio of dominant eigenvalue of school matrices over lockdown 3 reported as median (95% CI).

Susceptibility/ Infectiousness	Attendance	Ratio
1. Equal	Only Primary	1.6 (1.5 - 1.8)
	Only Secondary	1.6 (1.5 - 1.7)
	All Schools	2.4 (2.2 - 2.5)
2. Davies et al	Only Primary	1.2 (1.1 - 1.3)
	Only Secondary	1.2 (1.1 - 1.3)
	All Schools	1.4 (1.3 - 1.5)
3. ONS 1	Only Primary	1.2 (1.2 - 1.3)
	Only Secondary	1.2 (1.2 - 1.3)
	All Schools	1.6 (1.5 - 1.7)
4. ONS 2	Only Primary	1.2 (1.1 - 1.3)
	Only Secondary	1.2 (1.1 - 1.3)
	All Schools	1.5 (1.4 - 1.6)
5. Viner et al	Only Primary	1.4 (1.3 - 1.4)
	Only Secondary	1.3 (1.2 - 1.4)
	All Schools	1.8 (1.7 - 1.9)

Table S3 Expected resultant R_0 if schools were reopened for different baseline values of R_0 reported as median (95% CI)

Baseline R	Attendance	1. Equal	2. Davies et al	3. ONS 1	4. ONS 2	5. Viner et al
0.8	All Schools	1.9 (1.8 - 2.0)	1.2 (1.1 - 1.2)	1.3 (1.2 - 1.3)	1.2 (1.1 - 1.3)	1.5 (1.4 - 1.5)
	Only Primary	1.3 (1.2 - 1.4)	1.0 (0.9 - 1.0)	1.0 (0.9 - 1.1)	1.0 (0.9 - 1.0)	1.1 (1.0 - 1.2)
	Only Secondary	1.3 (1.2 - 1.4)	1.0 (0.9 - 1.0)	1.0 (0.9 - 1.1)	1.0 (0.9 - 1.0)	1.1 (1.0 - 1.1)
1	All Schools	2.4 (2.2 - 2.5)	1.4 (1.3 - 1.5)	1.6 (1.5 - 1.7)	1.5 (1.4 - 1.6)	1.8 (1.7 - 1.9)
	Only Primary	1.6 (1.5 - 1.8)	1.2 (1.1 - 1.3)	1.2 (1.2 - 1.3)	1.2 (1.1 - 1.3)	1.4 (1.3 - 1.4)
	Only Secondary	1.6 (1.5 - 1.7)	1.2 (1.1 - 1.3)	1.2 (1.2 - 1.3)	1.2 (1.1 - 1.3)	1.3 (1.2 - 1.4)
1.2	All Schools	2.9 (2.7 - 3.0)	1.7 (1.6 - 1.8)	1.9 (1.8 - 2.0)	1.8 (1.6 - 1.9)	2.2 (2.0 - 2.3)
	Only Primary	2.0 (1.8 - 2.1)	1.4 (1.3 - 1.5)	1.5 (1.4 - 1.6)	1.4 (1.3 - 1.5)	1.6 (1.5 - 1.7)
	Only Secondary	1.9 (1.7 - 2.0)	1.4 (1.3 - 1.5)	1.5 (1.4 - 1.6)	1.4 (1.3 - 1.5)	1.6 (1.5 - 1.7)

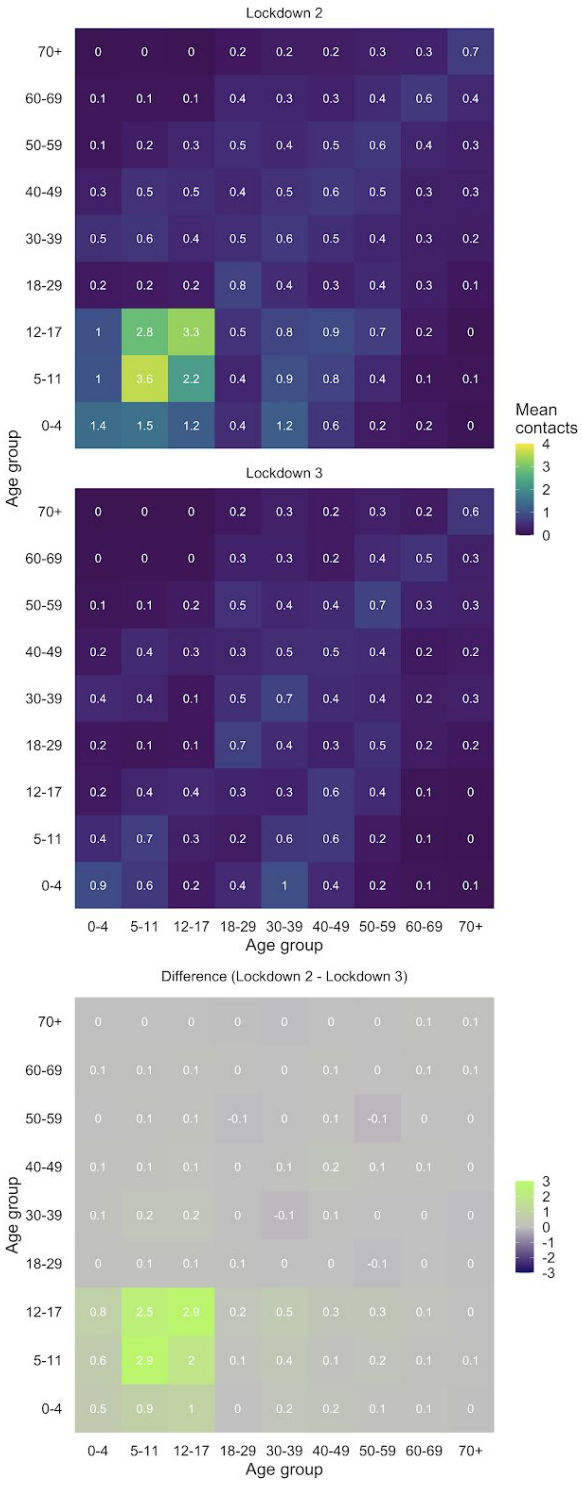

Figure S1: Contact matrix for all contacts in England by age comparing Lockdown 2 and Lockdown 3 and the absolute difference of the cells of the matrices. Contacts truncated to 50 contacts per participant. Lockdown 2 data from *5th November to 2nd December 2020 and Lockdown 3 data from 5th to 18th of January 2021*

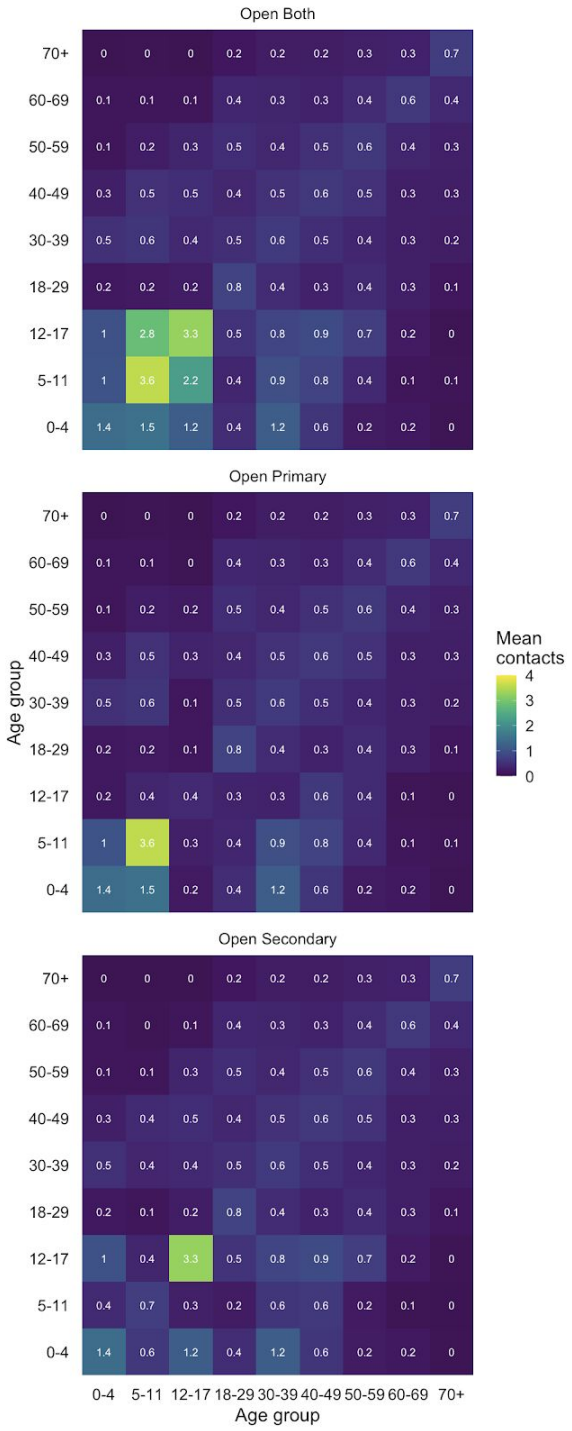

Figure S2: Contact matrix for Scenarios included in analysis of school reopening. For all schools open the matrix calculated for Lockdown 2 was used. *Scenarios with Primary or Secondary schools closed replaced the 5-11 or 12-17 (respectively) column and row replaced with those calculated for Lockdown 3.* Contacts truncated to 50 contacts per participant. Lockdown 2 data from *5th November to 2nd December 2020 and Lockdown 3 data from 5th to 18th of January 2021*

Source	Child		Adult		Risk ratio (95% CI)
	Positive	Negative	Positive	Negative	
National seroprevalence					
National Institute for Public Health and the Environment,[7] 2020	5	581	69	2445	0.31 (0.13-0.77)
Pollán et al,[36] 2020	388	11034	2712	46941	0.62 (0.56-0.69)
Hallal et al,[38] 2020	46	3353	303	21294	0.97 (0.71-1.31)
Regional or municipal seroprevalence					
Biggs et al,[40] 2020	0	48	19	629	0.34 (0.02-5.54)
Shakiba et al,[39] 2020	24	110	97	320	0.77 (0.51-1.15)
Stringhini et al,[41] 2020	33	422	186	2125	0.90 (0.63-1.29)
Nawa et al,[42] 2020	0	98	3	641	0.93 (0.05-17.88)
Postoutbreak seroprevalence					
Weis et al,[44] 2020	1	57	51	511	0.19 (0.03-1.35)
Pagani et al,[43] 2020	52	423	866	2,802	0.46 (0.36-0.60)
Streeck et al,[45] 2020	5	50	132	725	0.59 (0.25-1.38)
Virus prevalence					
Gudbjartsson et al,[32] 2020	0	848	100	12132	0.07 (0.00-1.15)
Lavezzo et al,[33] 2020	3	464	70	2275	0.22 (0.07-0.68)
Public Health Agency of Sweden,[34] 2020	3	482	17	2069	0.73 (0.21-2.52)
Office for National Statistics,[35] 2020	18	5959	96	29728	0.94 (0.57-1.55)

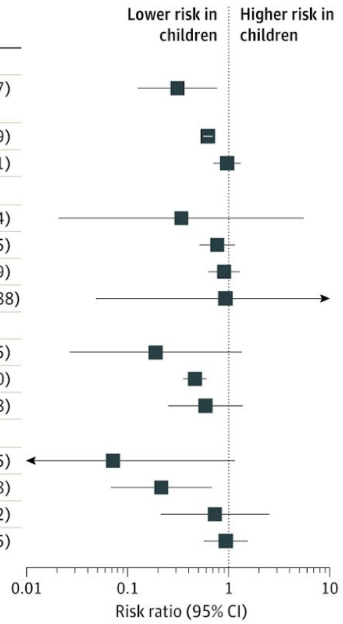

Figure S3: Ratios of the Prevalence of Severe Acute Respiratory Syndrome Coronavirus 2 Infection in Children and Adolescents Compared With Adults in Population Screening Studies. *Taken from Viner et al[6] (Figure 4 in their paper)*

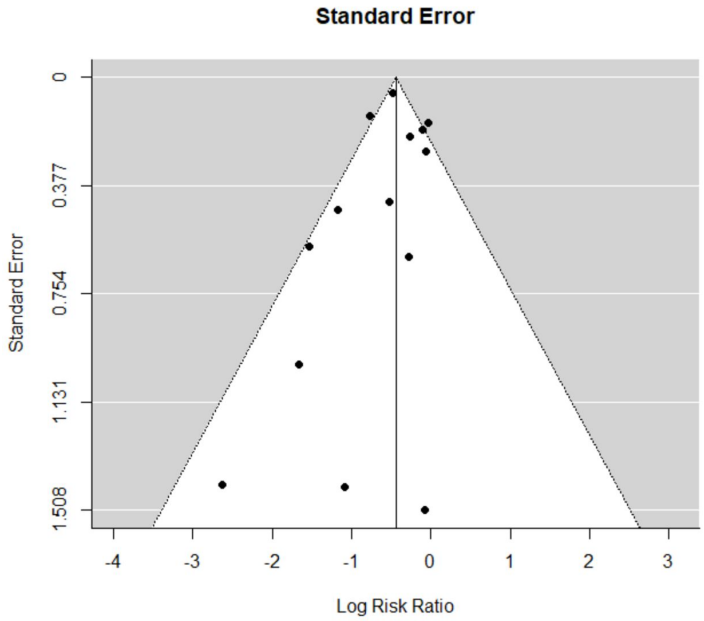

Figure S4: Funnel plot of estimates from Viner et al. *p = 0.067 for Egger's regression test for funnel plot asymmetry*

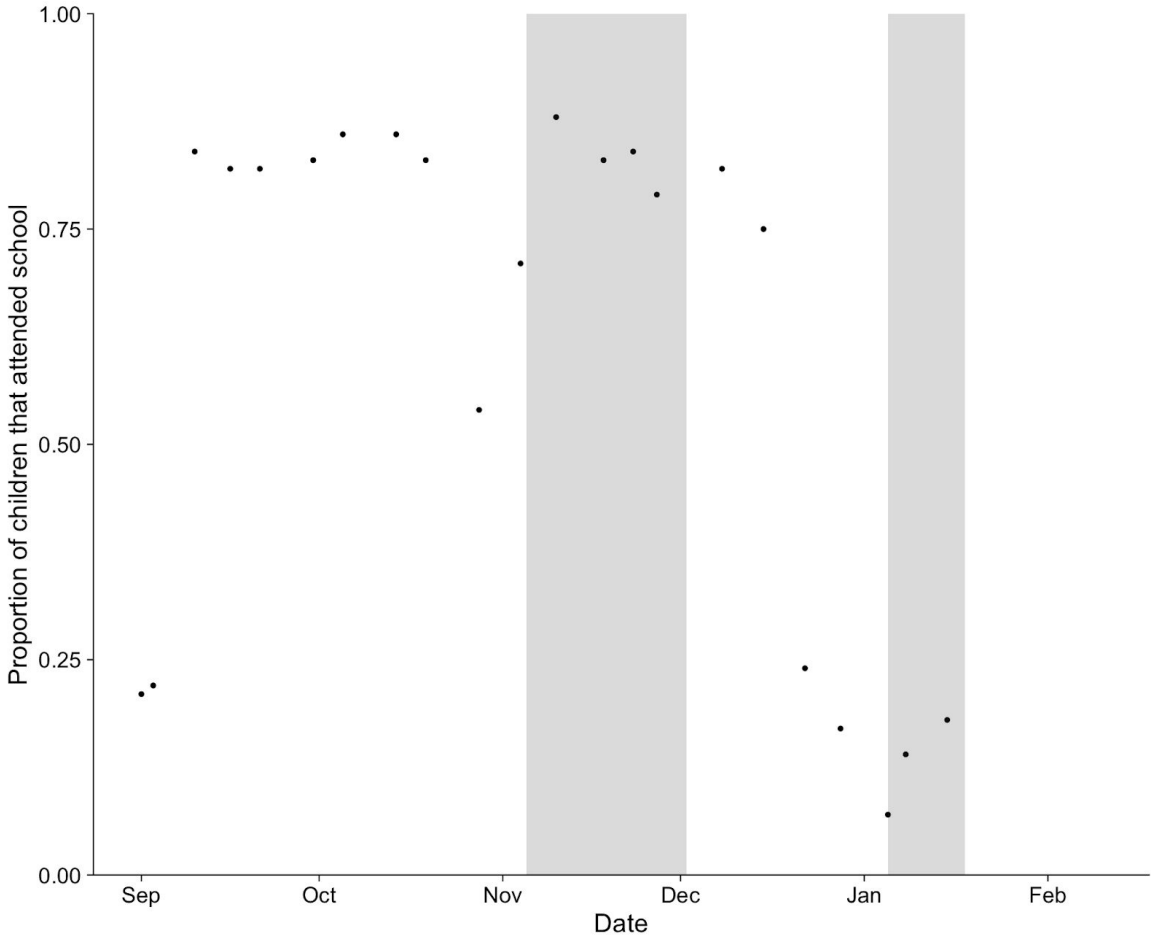

Figure S5: The proportion of child participants who attended school on the day when contacts are recorded (with weekends removed). Grey bands represent the periods over which data used for this analysis was recorded (second and third lockdown).