SARS-CoV2 susceptibility and transmission risk in children: an overview of current evidence from Public Health England's surveillance work

Purpose

1. This paper summarises evidence on what is known about susceptibility to infection and transmission dynamics in children. It briefly references evidence from the international literature but draws primarily on information from a range of surveillance systems and studies initiated by Public Health England (PHE) since the beginning of the COVID-19 pandemic. The focus of the paper is on implications of findings for educational settings in England.

2. The paper begins with an overview of overarching evidence on exposure rates and susceptibility to SARS-CoV2 in children before turning to address, in turn, evidence on transmission risk to and from children and young people in (i) households and the community; and (ii) educational settings. The focus of this paper is on children and young people, up to the ages of 16-19 years depending on the country source of the report. It does not consider evidence relating to young people of university age.

3. The paper has been produced as an evidence update for members of NERVTAG.

Overall risk of SARS-CoV2 infection and COVID-19 in children

4. Children are less likely to be hospitalised, need intensive care admission or die from COVID-19 compared to adults and, particularly, older adults [1,2]. The difference is particularly evident in children younger than 10 years compared to those aged 10-19 years [1]. A small proportion of children may develop severe disease with features of severe Kawasaki- and Toxic Shock Syndrome, but the relationship between this new clinical syndrome and SARS-CoV-2 infection remains unclear [3,4].

5. Population-level seroprevalence studies help give an indication of the extent of exposure to SARS-CoV2, and rates of infection, among children. Two PHE-led studies offer insights in this regard, covering the period 1st February to 2nd August 2020:

    a. The PHE Seroepidemiology Unit (SEU) and paediatric hospital survey: a collection of residual serum samples from routine microbiological testing;

    b. "What's the Story": a representative household survey that collects sera from healthy children and adolescents under the age of 25 years in England.

6. Both these analyses showed initially very low seroprevalence rates among children (0.5-0.8% depending on the study) in February-March, rising to a peak in April (in the range of 3.8-6.1% depending on the study) before declining in May (Appendix 1) – mirroring the longitudinal picture seen in adults. "What's the Story" data indicate an uplift in prevalence in the June-August period although confidence intervals overlap with previous periods.

7. The SEU seroprevalence data demonstrate a small but non-significant increase in antibody positivity rates from children to adults but with wide confidence intervals because of small sample sizes (Appendix 1)[1]. Preliminary data from schools surveillance (the sKIDS study – see further detail below) also show similar seropositivity rates among staff and students. Nationally,

[1] Note this this is for the period February-June 2020 – revised estimates up to August are being generated currently.

Office for National Statistics data suggest no difference in infection rates in children compared with adults, but this assessment is based on PCR positivity rather than serology data [5].

Susceptibility to COVID-19 in children compared to adults

8. A meta-analysis of international contact-tracing studies – almost all of which originated from China – published in May 2020 found that children had a substantially lower (56%) odds of being an infected contact compared with adults [6]. However, the case definition in all of these studies was based on RT-PCR positivity, not serological testing, limiting conclusions that can be drawn about odds of secondary infection in children from these data. Data published in a recent, large modelling study using data from China, Italy, Japan, Singapore, Canada and South Korea found that susceptibility to infection in people aged under 20 was around half of those aged 20 and over [7].

9. Taken together, these data suggest that (i) seroprevalence rates in children are slightly lower than in older age groups (possibly explained by lower rates of exposure among children during lockdown, although clear inferences are limited by overlapping confidence intervals); and (ii) children may be less likely to develop symptomatic infection compared to adults.

Transmission to and from children in households and the community

10. International data from community-based studies in Ireland [8] and France [9] (the latter study carried out in an area of high background transmission) spanning all contact between participants, show limited evidence of child-child and child-adult transmission, despite similar viral infection/load in children when compared with adults [10].

11. Available evidence suggests children often acquire infection from others in household settings [for example, 11]. Important data in this regard come from RAPiD-19, a study conducted by PHE with collaborators from across the UK, which recruited children of 215 health professionals in England to evaluate transmission from these workers to household members. In this study, 12% of children of healthcare workers tested COVID-19 positive overall, varying between 2% of children of PHE staff to 17% of children of NHS clinical staff (including GPs). The observed attack rate in children of NHS clinical staff with confirmed COVID-19 was 40%, with evidence of clustering of seropositivity within families – i.e. if one child in family is positive, then nearly all children are positive in the family. In the remaining families, if one child was seronegative, then all children were seronegative [12].

12. Children can however transmit to other children and to adults, especially those aged 10 and over within the household setting, once they have acquired infection. A household contact-tracing exercise of nearly 60,000 contacts in South Korea found that in instances where the index case was aged 10-19[2], the percentage of positive household contacts identified was 18.6% (14.0-24.0), higher than any other single age group in the study, although the proportion of outside-household contacts testing positive was comparatively low [13].

13. PHE data also confirm that children can transmit infection within a household setting. Data come from two sources:

    a. The FF100 study, following up the first few hundred cases of COVID-19 in the UK and their household contacts (amounting to 667 individuals residing in 213 homes);

[2] This study did not consider primary cases, so it is not possible to comment on the direction of transmission to the index case.

b. Enhanced Surveillance of Household Contacts (HoCo) – an extension to FF100 focused on households of confirmed index cases; and

14. In FF100, based on probable and PCR-confirmed cases, modelled secondary attack rates indicated that people living in households where the primary case was aged under 19 had a risk of acquiring the infection that was more than 6 times greater than households where the initial cases were aged 19-64 (appendix 2). These findings suggest that children may transmit SARS-CoV2 more efficiently that adults in a household setting, (though there were only 5 households with a child as a primary case).

15. In the HoCo study, secondary infection rates (based on serology and PCR) among contacts who were children were similar to those in adults (see appendix 3). Households with children as index cases were recruited later in the study, and most are still awaiting serology data.

16. Taken together, findings from these studies suggest that transmission risk to and from children in household settings is significant, but that observed infection rates are greatest in household contexts where the probability of exposure is high (children of clinical workers, for examples).

Transmission to and from children in educational settings

17. Evidence from schools and other educational settings indicates low risk of transmission in children of nursery or primary school age. There is insufficient evidence yet available to give a clear picture of risk for children of secondary school age. It nevertheless appears that risk accrues mainly to staff in these settings.

18. A PHE-led rapid review of transmission of COVID-19 in school settings and interventions to reduce the transmission produced in July 2020 considered evidence from the international literature on this topic [14]. The review identified 3 epidemiological case series published from 1st January 2020 to 18th June 2020, from Australia, France and Ireland [15,16,17]. All 3 studies considered onward transmission among children who were contacts of primary cases. Significant limitations in data completeness do not permit secondary attack rates to be calculated but reported secondary case numbers in these studies were very low (range: n=1-2). Two of the three studies examined whether child-to-teacher transmission occurred in their focus setting and found no evidence that it had [15,16].

19. Literature findings are broadly supported by primary data on transmission in educational settings available to PHE, and which derive from two sources:

    a. The COVID-19 Surveillance in KIDs (sKID) study, launched in May 2020; and

    b. Secondary analysis of reports to PHE Health Protection Teams (HPTs) of possible or confirmed outbreaks linked to educational settings in England.

    In evaluating this evidence, it is important to consider the global context of service provision in the education sector during the pandemic. Data from the Department for Education (DfE) show that estimated attendance across all year groups from nursery through to year 12 rose from 475,000 on 01/06/2020 to 1,608,000 on 09/07/2020 [18]. Over the same period, the estimated number of open educational settings rose from 20,500 to 22,700[3]. By comparison, school census data gathered by the Office for National Statistics in 2019/20 report an attendance

[3] Although educational settings have been open to vulnerable children and those of keyworkers throughout lockdown (from 23/03/20 onwards), formal re-opening to all children began on 1st June, starting with nursery, reception, year 1 and year 6 pupils. From 15th June, secondary schools, sixth form and further education colleges were asked to provide face-to-face educational support to students in years 10 and 12.

headcount of 8,890,357 in England that year, spanning settings of all types, and show that 24,360 school settings were open over that year [19].

20. The sKID study has so far recruited 9,000 participants (both children and staff members) across 138 schools in England. In 49 of these schools, swab tests and blood tests have been offered to participants at the beginning and end of term. In the remaining 89 schools, weekly COVID-19 swab tests have been performed. Of more than 30,000 swab tests so far performed via these routes for those participating in this study, 6 have returned positive results. Five of the six individuals with positive results were staff members for whom there is no evidence that infection was acquired within the school. The sole positive test in a child occurred in a household where the mother (a healthcare worker) had previously tested positive.

21. Data on confirmed clusters and outbreaks of COVID-19 cases in educational settings[4] in England have also been collated by PHE (see appended paper for further details of the approach used), and detailed further investigation is underway for all these situations to build a complete picture. For June, the month for which data are currently most complete, 170 situations were reported in total, in 69 (40%) of which there were ultimately no confirmed cases, there was a single confirmed case in 67 (39%), a confirmed cluster of co-primary cases (within the same household in 4 (2%) and a confirmed outbreak (defined as two or more confirmed cases within a 14 day period linked to the setting) in 30 (18%).

22. In the confirmed clusters (i.e. co-primary cases occurring in the same household), the index case acquired the infection from a known source outside the educational setting, and the source identified in all of these instances was another household member (parents in 4 of the 5 households involved). Children in these situations were tested as part of wider household testing for confirmed cases.

23. For the 30 situations that were confirmed as outbreaks,15 concerned transmission between staff members with no evidence of transmission to children. Seven outbreaks involved evidence of transmission from staff members to children. In six outbreaks there was evidence suggesting transmission from a child to a staff member (never more than one staff member was affected however, in any given outbreak where transmission from a child was thought to have occurred as the primary event). Two outbreaks involved potential child-child transmission. Two of the outbreaks occurred in secondary schools, both involving staff-staff transmission only. There were also differences in patterns of secondary spread from index cases: where the index case was a child, the maximum number of secondary cases for any outbreak across the month was 2 (compared with 9 for staff members).

24. Analysis against pillar 2 testing data identified a strong correlation between number of outbreaks in educational settings and regional COVID-19 incidence (0.51 outbreaks for each new SARS-CoV-2 infection per 100,000 in the community; p=0.001). We estimate that there were 0.5, 4.8 and 1.6 outbreaks per 1,000 settings per month in early years, primary schools and secondary schools over the month of June – although it should be noted that attendance levels across open settings were much higher for early years and primary schools than secondary schools.

25. Finally, emerging evidence from qualitative research work as part of the sKID study offers insights on the practical feasibility of implementing COVID-19 protective measures in schools. In particular, this work points to the challenges of maintaining social distancing measures in educational settings for children in this age group, and the perceived value of basic infection prevention and control measures including hand washing.

[4] "Educational settings" incorporate nurseries, preschools, infant schools, junior schools, primary schools, secondary schools, further education colleges, and settings for children who have special educational needs.

26. While the evidence above suggests an increasingly clear picture for primary school age children, there is more uncertainty for older children, who appear to have a greater proclivity to severe disease and for whom there is still insufficient data on transmission to form a clear view of risk. PHE seroprevalence data show increasing seroprevalence rates in children aged 10 and over, and especially for young adults, indicating higher exposure rates in these groups. In addition, recent literature evidence points to the potential for significant transmission from and between older children: in an outbreak investigation from Israel, for example, 153 cases of COVID-19 were identified in students (attack rate: 13.2%) and 25 staff members (attack rate: 16.6%) at a high school [20].

Summary

27. Available evidence from PHE surveillance systems show that children are almost as likely to get infected with SARS-CoV2 as adults, as observed through their antibody status. Given that there are nearly half as many confirmed COVID-19 cases in children up to 10 years compared to adults, it is likely that most infections are asymptomatic or mild and transient but with sufficient exposure to mount an antibody response.

28. In younger children, most infections are likely to be acquired in household settings. There is little evidence that they transmit more widely, even in educational settings, suggesting that closer, intimate contact is required for transmission from children to other children and adults to occur. This would suggest that children in bubbles and classes are at relatively low risk and that the highest risk is among staff members.

29. There is insufficient data from PHE systems currently to form a clear view of acquisition and transmission risk in older children, although international evidence suggests that risk of infection, disease and transmission is likely to be higher in older than younger children [21,22].

30. There is little evidence at this time of transmission to and from children in the wider community or educational settings, especially in nursery and primary schools to which large numbers of children returned in England in June and July 2020. However, the numbers of children who are likely to attend from September 2020 onwards would be substantially greater than during the summer mini-term just completed. Data from secondary schools are insufficient to form a clear assessment of risk at this time because attendance rates there have been much lower.

Recommendations (for consideration)

- Track and trace approaches for household contacts should be optimised to identify staff and students with infection quickly to reduce the risk of introduction into school settings.
- Given the seemingly greater risk of transmission in staff than children, emphasis should be placed on increased staff support and education regarding infection risk in the community, infection control between staff in school, and where possible between staff and students.
- Evidence suggests that rates of transmission in pre-school and primary school settings are low. Qualitative reports indicate that social distancing between younger children is hard to achieve; there should, therefore, be a clearer focus on hand washing and other IPC measures
- A different focus is likely to be needed in secondary schools, where the shortage of available evidence means that vigilance will need to be maintained. In particular, generating high quality surveillance data – especially in the first few months following re-opening in September – will be essential to robust assessment of transmission risk.

Appendix 1: data from the PHE SEU and "What's the Story" studies

31. Data from the SEU derive from analysis of residual samples from the SEU and paediatric hospital collections collected from 1st February to 2nd August 2020. This subset of residual SEU and paediatric samples was tested using the Abbot assay.

32. Results of testing using these assays show a large increase in adjusted prevalence of SARS-CoV2 antibodies in this group from an initial phase from February/March during which community transmission was at low levels, through to the peak of the epidemic curve in England in April, when community transmission was widespread. Adjusted prevalence rates later reduced.

date range	pos	equiv	neg	total	% pos (95% CI)	adjusted prevalence (95% CrI)
1 Feb - 31 Mar	2	6	435	443	1.8% (0.8% - 3.5%)	0.8% (0% - 2.5%)
1 - 30 Apr	39	4	604	647	6.6% (4.9% - 8.8%)	6.1% (4.1% - 8.4%)
1 - 31 May	72	11	978	1061	7.8% (6.3% - 9.6%)	7.3% (5.6% - 9.2%)
1 June - 2 Aug	55	10	1997	2062	3.2% (2.4% - 4.0%)	2.4% (1.3% - 3.4%)

Table A1: summary of SEU and Paediatric (unweighted) prevalence estimates (ages 1 – 19) by period of sampling, using the Abbott assay (neg<0.8 units, equiv 0.8-<1.4, pos>=1.4)

33. Breakdown analysis to plot out variations in seroprevalence by age group using PHE SEU data show that prevalence estimates for children were lower than any single adult age band, as shown below (figures below are based on data to early June only – updated estimates are being generated currently):

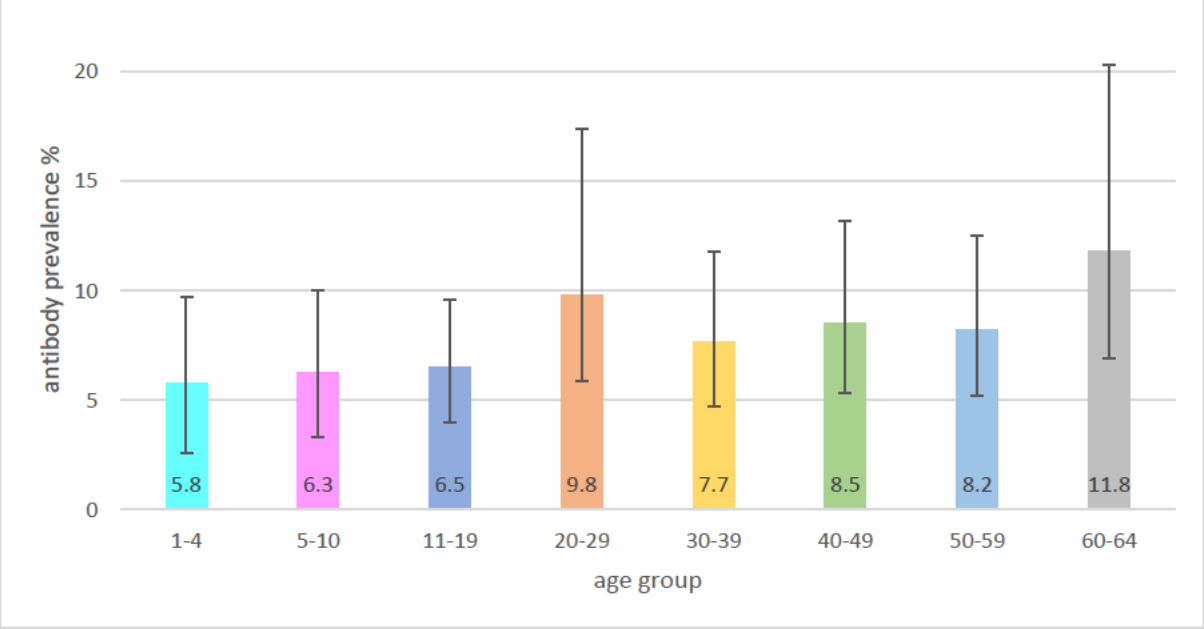

Figure A1: Region weighted % pos (with 95% CI) by age group, SEU and Paediatric collection data, 1st May – 10th June

34. Data from the "What's the Story" study presented here derive from analysis of samples collected between 1st February and 2nd August 2020. Findings from testing of these samples reveals a similar trend to the SEU data presented above.

date range	pos	equiv	neg	total	% pos (95% CI)	adjusted prevalence (95% CrI)
1 Feb - 31 Mar	0	1	105	106	1.4% (0.6% - 4.3%)	0.5% (0% - 3.6%)
1 - 30 Apr	7	2	192	201	4.5% (2.1% - 8%)	3.8% (1.2% - 7.5%)
1 - 31 May	4	0	139	143	2.7% (1% - 6.4%)	1.9% (0% - 5.8%)
1 June - 2 Aug	10	4	271	285	4.9% (2.8% - 7.8%)	4.2% (1.9% - 7.3%)

Table A2: summary of What's the Story (unweighted) Prevalence Estimates (ages 1 – 19) by period of sampling, using the Abbott assay (neg<0.8 units, equiv 0.8-<1.4, pos>=1.4)

Appendix 2: data from the FF100 study

Using data from the FF100 study, a mixed effects logistic regression analysis was performed using the household identification number as a random intercept. Gender, age group, household size and period of symptom onset of the primary case were use as categorical explanatory variables. Table A3 below shows the results of this analysis – with particular reference to the modelled secondary attack rates by age.

Explanatory variables	Estimated odds ratio		Estimated SAR	
	estimate	95% CI	estimate	95% CI
Gender of contact				
female	reference		0.34	0.28 to 0.41
male	0.89	0.51 to 1.58	0.33	0.26 to 0.39
Age group of contact				
18 or younger	**0.20**	**0.08 to 0.49**	**0.18**	**0.12 to 0.25**
19 to 34 inclusive	reference		0.41	0.32 to 0.51
35 to 64 inclusive	0.96	0.43 to 2.17	0.41	0.31 to 0.50
55 or older	0.99	0.41 to 2.41	0.41	0.29 to 0.54
Symptom onset in primary case				
Before 27/02	reference		0.41	0.29 to 0.52
27/02-29/02 inclusive	0.47	0.18 to 1.25	0.29	0.21 to 0.38
01/03-03/03 inclusive	0.85	0.31 to 2.31	0.38	0.28 to 0.48
after 03/03	0.44	0.16 to 1.22	0.28	0.19 to 0.37
Household size				
2	reference		0.42	0.31 to 0.53
3	0.77	0.31 to 1.90	0.38	0.28 to 0.47
4	0.59	0.22 to 1.56	0.34	0.24 to 0.43
5 or more	**0.24**	**0.08 to 0.74**	**0.21**	**0.11 to 0.32**
Age of primary case				
18 or younger	**6.30**	**1.10 to 36.02**	**0.61**	**0.36 to 0.86**
19 to 64 inclusive	reference		0.33	0.27 to 0.38
65 or older	0.72	0.22 to 2.41	0.28	0.13 to 0.43

Table A3: Estimated odds ratios and secondary attack rates from a mixed effects logistic regression model

Appendix 3: data from PHE enhanced surveillance of household contacts (HoCo study)

Using data from the HoCo study, secondary attack rates were calculated for participants based on (i) serological status, (ii) age of the index case and (iii) PCR positivity.

Table A4 below shows secondary attack rates by the age of the contact among those participants that had a serological follow up as part of the HoCo study. The overall secondary attack rate in children and young people up to the age of 18 was comparable with other age groups in the study.

Age group contact	Infected	Uninfected	Total	% infected (95% CI)
<=18	21	24	45	46.7% (31.7-62.1)
18 to 54	29	28	57	50.9% (37.3-64.4)
>=55	7	10	17	41.2% (18.4-67.1)
Total	57	62	119	47.9% (38.7-57.2)

Table A4: Secondary attack rates in contacts who have had serological follow up.

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