SARS-CoV-2 infection and transmission in primary schools in England in June–December, 2020 (sKIDs): an active, prospective surveillance study

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Summary

Background Little is known about the risk of SARS-CoV-2 infection and transmission in educational settings. Public Health England initiated a study, COVID-19 Surveillance in School KIDs (sKIDs), in primary schools when they partially reopened from June 1, 2020, after the first national lockdown in England to estimate the incidence of symptomatic and asymptomatic SARS-CoV-2 infection, seroprevalence, and seroconversion in staff and students.

Methods sKIDs, an active, prospective, surveillance study, included two groups: the weekly swabbing group and the blood sampling group. The swabbing group underwent weekly nasal swabs for at least 4 weeks after partial school reopening during the summer half-term (June to mid-July, 2020). The blood sampling group additionally underwent blood sampling for serum SARS-CoV-2 antibodies to measure previous infection at the beginning (June 1–19, 2020) and end (July 3–23, 2020) of the summer half-term, and, after full reopening in September, 2020, and at the end of the autumn term (Nov 23–Dec 18, 2020). We tested for predictors of SARS-CoV-2 antibody positivity using logistic regression. We calculated antibody seroconversion rates for participants who were seronegative in the first round and were tested in at least two rounds.

Findings During the summer half-term, 11 966 participants (6727 students, 4628 staff, and 611 with unknown staff or student status) in 131 schools had 40 501 swabs taken. Weekly SARS-CoV-2 infection rates were 4·1 (one of 24 463; 95% CI 0·1–21·8) per 100 000 students and 12·5 (two of 16 038; 1·5–45·0) per 100 000 staff. At recruitment, in 45 schools, 91 (11·2%; 95% CI 7·9–15·1) of 816 students and 209 (15·1%; 11·9–18·9) of 1381 staff members were positive for SARS-CoV-2 antibodies, similar to local community seroprevalence. Seropositivity was not associated with school attendance during lockdown (p=0·13 for students and p=0·20 for staff) or staff contact with students (p=0·37). At the end of the summer half-term, 603 (73·9%) of 816 students and 1015 (73·5%) of 1381 staff members were still participating in the surveillance, and five (four students, one staff member) seroconverted. By December, 2020, 55 (5·1%; 95% CI 3·8–6·5) of 1085 participants who were seronegative at recruitment (in June, 2020) had seroconverted, including 19 (5·6%; 3·4–8·6) of 340 students and 36 (4·8%; 3·4–6·6) of 745 staff members (p=0·60).

Interpretation In England, SARS-CoV-2 infection rates were low in primary schools following their partial and full reopening in June and September, 2020.

Funding UK Department of Health and Social Care.

Introduction

The declaration of COVID-19 as a pandemic led most countries to close their schools as part of their national lockdown measures,[1–3] with more than 1 billion children affected worldwide.[4] Although children are recognised to contribute to only a small proportion of confirmed COVID-19 cases and rarely develop severe or fatal disease,[5,6] their role in asymptomatic infection and transmission is uncertain. The proximity of young children in educational settings could lead to rapid transmission between the children and staff, their household contacts, and potentially the wider community. This is well described for other viral infections, including influenza, in which children are the main drivers of infection.[7,8] In

previous coronavirus outbreaks, school closure did not contribute to the control of these epidemics.[3] School closure affects educational attainment as well as the physical, social, and mental wellbeing of children,[3] especially among those from vulnerable and disadvantaged backgrounds.[9]

In England, a rapid increase in SARS-CoV-2 infections from early March, 2020, led to school closures on March 20, 2020, and wider lockdown on March 23, 2020.[10] However, children of key workers, including health-care workers, could attend school throughout lockdown.[11] Nationally, COVID-19 cases plateaued in mid-April, 2020, and then declined in May, 2020, allowing gradual easing of lockdown measures.[12] Preschool and some primary school

Research in context

Evidence before this study

We searched PubMed for articles published in English between Jan 1 and Dec 31, 2020, with the terms "COVID-19" or "SARS-CoV-2" with "school", "education", or "student" to identify publications relating to SARS-CoV-2 infections and COVID-19 cases in educational settings. The majority of publications were reviews and opinion pieces on the effects of school closures on disease transmission and child health. Some countries, such as Sweden and Iceland, kept their schools open during their lockdowns and found no increase in confirmed SARS-CoV-2 infections, COVID-19 cases, or severe cases in school-aged children (younger than 18 years). Other countries, such as Germany and England, reported limited infections and transmission in educational settings following the reopening of schools after the first lockdown. Published studies have been limited to surveillance and reporting of active infections in children and provide no information on asymptomatic infection and transmission in educational settings.

Added value of this study

In addition to swabbing for SARS-CoV-2 RNA to test for acute infection, we measured serum SARS-CoV-2 antibodies in students and staff in primary schools across England as a marker of previous infection. We found very low rates of SARS-CoV-2 infection estimated through nasal swab RT-PCR during the summer half-term (June–July) when some primary school years returned to school and during the autumn term (September–December) when all primary school years returned to school. In seronegative staff and students at recruitment, we found almost no seroconversions during the summer half-term and only 5% seroconversions during the autumn term.

Implications of all the available evidence

We found very low rates of symptomatic or asymptomatic SARS-CoV-2 infection in students and staff following partial and full reopening of primary schools in England. Community SARS-CoV-2 infection rates were low during the summer half-term and high during the autumn term. Our results indicate that primary schools were not sites of significant transmission, before the emergence of new variants of SARS-CoV-2 in the UK. Further work is needed to understand the effect of new variants within educational settings.

years (nursery [age 3–4 years], reception [4–5 years], year 1 [5–6 years], and year 6 [10–11 years]) reopened from June 1, 2020, and some secondary school years (years 10 [14–15 years] and 12 [16–17 years]) reopened from June 15, 2020, until the end of the summer half-term in mid-July, 2020.[13] Strict physical distancing and infection control measures were implemented, including smaller class sizes and clustering of staff and students into so-called bubbles.[13] These measures, along with low community infection rates (0·7 per 100 000 population), were associated with very few SARS-CoV-2 infections[14] or outbreaks during the summer half-term,[15] leading to full reopening of all school years in September, 2020,[13] when daily SARS-CoV-2 infection rates were 0·6 per 100 000 population, increasing to 4·7 per 100 000 by December, 2020.[14]

The decision to reopen schools has been divisive.[2,9] Despite the clear benefits of children returning to school, parents and school staff remain concerned about putting the students, staff, and their household members at risk of infection.[16,17] To investigate this risk, Public Health England (PHE) initiated a study, COVID-19 Surveillance in School KIDs (sKIDs), to monitor the incidence of acute asymptomatic and symptomatic SARS-CoV-2 infection and transmission in primary schools when they partially reopened in June, 2020.

Methods

Study design and population

sKIDs, an active, prospective surveillance study, involved convenience sampling of primary schools into two groups. One group received weekly swabbing to estimate the incidence of acute asymptomatic and symptomatic SARS-CoV-2 infection and transmission in students and staff. Because of concerns about asymptomatic infections and transmission, another group of schools received both nasal swabbing and blood sampling for SARS-CoV-2 antibodies to assess previous infection at recruitment and at the end of each school term. Serum antibodies provide a robust measure of past exposure to SARS-CoV-2, capturing symptomatic, asymptomatic, and mild, transient infections.

In both groups, head teachers sent the study information pack to staff and parents and asked them to return a signed consent form before the first sampling day.[18] The protocol is available online and was approved by PHE Research Ethics Governance Group (reference NR0209; May 16, 2020).

Procedures

In the weekly swabbing group, 200 primary schools across English regions with 30 or more students attending during the summer half-term (from June 15 to mid-July, 2020) for at least 4 weeks were approached by the UK Department of Education to take part. A nasal swab was taken on the same day every week and couriered to PHE for testing. The sKIDs investigators worked with the Department of Education, local healthcare trusts, health protection teams, and the local authority to identify a local experienced person, such as a local nurse or first aider, to take nasal swabs from students and supervise staff members taking their own swabs.

In the blood sampling group, schools were approached in five regions where a paediatric investigation team could be assembled: North London, East London, Oxford, Derby, and Manchester. Participating staff and students had nose and throat swabs and a blood sample taken by the investigation team in June (round 1: June 1–19), mid-July (round 2: July 3–23), and end of the autumn term (round 3: Nov 23–Dec 18). Blood samples and swabs were taken by sKIDs investigators (doctors, nurses, and phlebotomists) in school premises. Local anaesthetic cream was offered to all students.

In both groups, before the first sampling day, staff and parents completed a questionnaire about demographics, risk factors, and school attendance during lockdown, as well as COVID-19 symptoms or confirmed infections in the household. Questionnaires about COVID-19 symptoms and positive tests for participants and their household members were completed at each testing round.

Throughout the summer half-term, investigators worked closely with schools to test unwell staff and students for SARS-CoV-2 infection through local testing centres or by posting swab kits to their homes. Head teachers and participants were asked to notify PHE if any participant tested positive for SARS-CoV-2 or was a contact of a positive case. SARS-CoV-2-positive staff and students were invited to enrol in a household transmission study, in which all household members were swabbed by the sKIDs investigation team and had blood samples taken for antibody testing 4–6 weeks later. The weekly swabbing group was stopped after the summer half-term because very few positive results were yielded.

The swabs were tested by a quantitative RT-PCR (RT-qPCR) assay on an Applied Biosystems 7500 FAST system (ThermoFisher Scientific, CA, USA) targeting a conserved region of the open reading frame 1ab (ORF1ab) gene of SARS-CoV-2.[19] Positive RT-qPCR results were reported to the participant, local investigator, head teacher, and local PHE health protection team, typically within 48 h; any positive results with a cycle threshold value greater than 35 were retested by extraction and concentration to verify the initial result. The participant and household members self-isolated as per national guidance. Public health risk assessment was undertaken with the school to decide additional measures, including isolation of the participant's class bubble. Serological tests were performed on the Abbott Architect using a chemiluminescent microparticle immunoassay to detect IgG antibodies to SARS-CoV-2 nucleoprotein (Abbott Commerce, Chicago, IL, USA). This assay has a seropositivity threshold of 0.8.[20]

Statistical analysis

Participants were linked to the national surveillance database held at PHE, which includes daily reports of all SARS-CoV-2 RT-qPCR tests. Participants were linked by name, date of birth, sex, and region to ascertain whether they had tested positive for SARS-CoV-2 between testing rounds. Analysis of swab positivity rates during the summer half-term included both study groups. Where participant status was unknown, we assumed that the student-to-staff ratio in participants with missing information was the same as the proportion with available information; these participants with missing data were included as denominators to estimate weekly infection rates.

Data that did not follow a normal distribution are described as median with IQR. Categorical data are described as proportions and compared with the χ^2 test or Fisher's exact test. We tested for predictors of SARS-CoV-2 antibody positivity using logistic regression. We built a multivariable regression model using likelihood ratio tests and included factors that were significant, or of a priori interest, in the univariable analysis. These factors included demographics, school attendance during lockdown, and additional children in the household (students only). Being unwell with symptoms of COVID-19, having confirmed COVID-19, and having household members with previous confirmed COVID-19 were assessed in the univariable analysis only because of their strong correlation with seropositivity. The univariable analysis included all participants, followed by multivariable analysis including participants with complete questionnaire data to allow consistent results. We tested differences between schools by adjusting for clustering in the final multivariable models. Wald tests were used to generate global p values. The 95% CIs for antibody positivity include clustered SEs by school. We analysed characteristics of dropouts in students and staff in subsequent rounds using univariate and multivariable logistic regression, adjusted for sex, age, ethnicity, region, and round 1 antibody test results. Participants were classified as included in rounds two and three if they provided a blood or swab sample during those visits. We calculated antibody seroconversion rates for all participants who were tested in at least two rounds and were negative in the first round. We assessed factors associated with seroconversion using Poisson regression, adjusted for sex, ethnicity, region, participant type, proportion of students at the school who receive free school meals, and follow-up time, and clustered by school. An overall seroconversion rate was estimated using participants who were tested at the beginning and end of the surveillance (rounds 1 and 3); all other analyses included seroconversions in participants who were tested at least twice during the surveillance period.

Data were managed in Microsoft Access and analysed using Stata (version 15.0).

Role of funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

In June, 2020, 11 966 participants in 131 schools were recruited across England (appendix p 2), with a median of 93 (IQR 61–156) participants in 86 schools taking part in weekly swabbing and 43 (28–68) participants in 45 schools involved in serology testing. Of the 11 355 (94·9%) participants with completed questionnaires, 6727 (59·2%) were students and 4628 (40·8%) were staff (table 1). Of the 40 501 swabs taken in June and July, 2020, 23 339 (57·6%) with available

information were from students and 15 288 (37·7%) were from staff. The number of swabs taken in the weekly swabbing group of the surveillance increased weekly as more participants agreed to take part until the first week of July, 2020, and then declined as schools closed for the summer holidays. One student and five staff members had detectable SARS-CoV-2 from their nose or throat swab. Three staff members (two previously symptomatic and one asymptomatic) had very high RT-qPCR cycle threshold values (>39),

	Students (n=6727)	Staff (n=4628)	Unknown (n=611)	Total (n=11 966)
Sex				
Female	3374/6653 (50·7%)	3902/4600 (84·8%)	2	7278/11 255 (64·7%)
Male	3279/6653 (49·3%)	698/4600 (15·2%)	0	3977/11 255 (35·3%)
Missing sex	74	28	609	711
Ethnicity				
White	4016/5389 (74·5%)	3403/4019 (84·7%)	1	7420/9409 (78·9%)
Mixed or multiple ethnic groups	415/5389 (7·7%)	94/4019 (2·3%)	0	509/9409 (5·4%)
Black or Black British	217/5389 (4·0%)	128/4019 (3·2%)	0	345/9409 (3·7%)
Asian or Asian British	576/5389 (10·7%)	344/4019 (8·6%)	0	920/9409 (9·8%)
Other ethnic group	165/5389 (3·1%)	50/4019 (1·2%)	0	215/9409 (2·3%)
Missing ethnicity	1338	609	610	2557
Study group				
Weekly swabbing only (86 schools)	5911 (87·9%)	3247 (70·2%)	611	9769 (81·6%)
Participant numbers in swabs schools	61 (33–102)	36 (23–48)	4 (2–8)	93 (61–156)
Swabs per person in swab schools	4 (3–5)	4 (4–5)	3 (2–4)	4 (3–5)
Blood sampling (45 schools)	816 (12·1%)	1381 (29·8%)	0	2197 (18·4%)
Participant numbers in blood schools	13 (8–36)	28 (17–36)	··	43 (28–68)
Swabs per person in blood schools	2 (1–2)	2 (1–2)	1 (1–1)	2 (1–2)
Total numbers of swabs taken	23 339	15 288	1874	40 501
Swabs per school	127 (30–306)	93 (55–163)	8 (4–21)	227 (103–467)
Age, years				
4–6	2515/5949 (42·3%)	NA	0	··
7–9	1377/5949 (23·1%)	NA	0	··
10–12	2057/5949 (34·6%)	NA	0	··
20–29	NA	68/489 (13·9%)	0	··
30–39	NA	139/489 (28·4%)	0	··
40–49	NA	121/489 (24·7%)	0	··
50–59	NA	125/489 (25·6%)	0	··
≥60	NA	36/489 (7·4%)	0	··
Missing	778	4139	0	4917
Region in England				
East Midlands	1194 (17·7%)	611 (13·2%)	52	1857 (15·5%)
East of England	259 (3·9%)	141 (3·0%)	29	429 (3·6%)
London	950 (14·1%)	1280 (27·7%)	73	2303 (19·2%)
North East	583 (8·7%)	282 (6·1%)	79	944 (7·9%)
North West	405 (6·0%)	375 (8·1%)	1	781 (6·5%)
South East	513 (7·6%)	298 (6·4%)	40	851 (7·1%)
South West	523 (7·8%)	332 (7·2%)	39	894 (7·5%)
West Midlands	1985 (29·5%)	1152 (24·9%)	19	3156 (26·4%)
Yorkshire and the Humber	315 (4·7%)	157 (3·4%)	279	751 (6·3%)

Data are n (%), n, or median (IQR). Percentages might not sum to 100% due to rounding. NA=not applicable.

Table 1: Characteristics of staff and students in the participating schools (June to mid-July, 2020)

consistent with very low viral load, and when the samples were concentrated and re-analysed they tested negative; all three were also antibody negative 4–6 weeks later. The asymptomatic student was a child of a health-care worker who had been symptomatic and RT-qPCR positive 4 weeks previously. Therefore, after adjusting for missing status (ie, staff or student), one student (of 24 463 swabs taken) and two staff members (of 16 038 swabs taken) had confirmed SARS-CoV-2 infection. We estimated a SARS-CoV-2 infection rate of 4·1 (95% CI 0·1–22·8) per 100 000 students and 12·5 (1·5–45·0) per 100 000 staff per week of testing during the summer half-term. All household contacts were offered a nasal swab and tested negative; none became symptomatic during follow-up (appendix p 3).

In blood sampling schools, at recruitment (the first two weeks of June, 2020), 300 (13·7%; 95% CI 10·8–16·9) of 2197 participants tested positive for SARS-CoV-2 antibodies: 91 (11·2%; 7·9–15·1) of 816 students and 209 (15·1%; 11·9–18·9) of 1381 staff members. Antibody positivity varied across the different English regions (p<0·001) and between students and staff (p=0·009), but was similar to the regional seroprevalence during the same week (figure 1).

For both students (table 2) and staff (table 3), after adjusting for the other variables in the final model, a school clustering effect was significant for staff members (p=0·0002) but not students (p=1·00). For both students and staff, seropositivity was associated with non-White ethnicity and health-care workers in the household (tables 2, 3). For students, region was a significant predictor of antibody positivity (p=0·020; table 2) and for staff seropositivity was significantly lower in Derby than in North London (adjusted OR 0·27, 95% CI 0·10–0·73; table 3). Seropositivity was not associated with school attendance during lockdown (p=0·13 for students and p=0·20 for staff) or staff contact with students (p=0·37). 20 (22·0%) of 91 seropositive students reported COVID-19-like illness compared with 122 (58·4%) of 209 staff members (p<0·001).

1618 (73·6%) of 2197 individuals were still participating in the surveillance in round 2 (end of summer half-term), 603 (73·9%) of 816 students and 1015 (73·5%) of 1381 staff members (appendix p 4). Multivariable logistic regression found the school region was a significant predictor of dropout for staff and students in round 2, and ethnicity for students only (appendix pp 5–6). 173 (12·1%; 95% CI 9·3–15·3) of 1430 returning participants were seropositive, including 56 (10·4%; 6·8–15·0) of 540 students and 117 (13·1%; 9·9–17·0) of 890 staff members. Of the 1897 sero-negative participants in round 1, 1254 were retested in round 2 and five (0·4%; 95% CI 0·1–0·9) seroconverted (figure 2). Seroconversion rates were not significantly different in students (four [0·8%] of 487; 95% CI 0·2–2·1) and staff (one [0·1%] of 767; 0·0–0·7; p=0·08).

In round 3 (end of autumn term), 1361 (61·9%) of 2197 participants were retested, including 442 (54·2%)
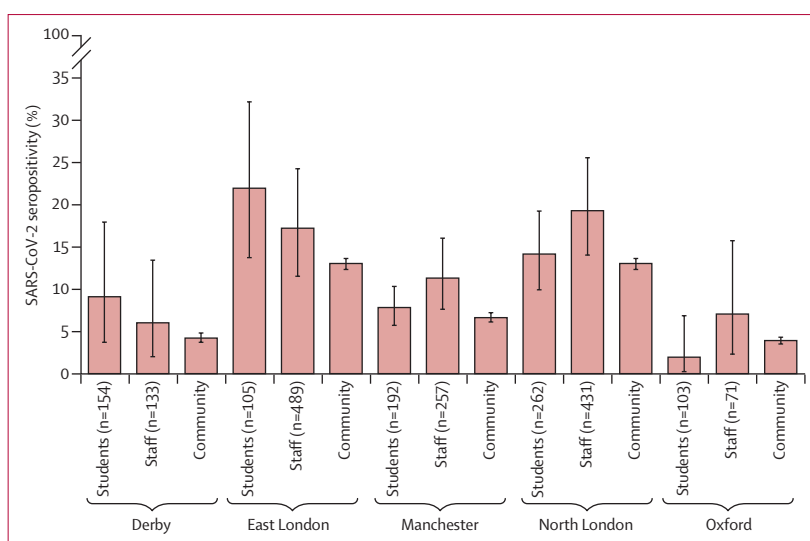

Figure 1: **Seropositivity in staff and students in primary schools in five English regions compared with regional seroprevalence during the first two weeks of June, 2020**
Community seroprevalence data were obtained from Ward et al (2020).[21] Error bars indicate 95% CIs.

of 816 students and 919 (66·5%) of 1381 staff members (appendix p 4). School region was a significant predictor of participation for staff and students (appendix pp 5–6). In students, age was also a significant predictor of participation in round 3 because children moving to secondary school in the 2020–21 academic year were not included. One (0·1%; 95% CI 0·0–0·6) of 900 participants, a staff member, was SARS-CoV-2 RT-qPCR positive in round 3. Linkage with surveillance data for students identified five additional cases during the autumn term, one of whom participated in round 3. There were no reinfections in staff or students. 136 (10·7%; 95% CI 8·7–13·0) of 1274 participants were seropositive, including 33 (8·6%; 5·8–12·2) of 384 students and 103 (11·2%; 9·2–14·3) of 890 staff members. Among students who were seronegative at round 1, 13 (5·1%; 95% CI 2·7–8·6) of 255 among those attending rounds 2 and 3, and three (3·7%; 0·8–10·3) of 82 among those attending rounds 1 and 3 sero-converted (figure 2). Among staff members who were seronegative at round 1, 28 (4·9%; 95% CI 3·3–7·0) of 569 members attending rounds 2 and 3 and seven (4·0%; 1·6–8·1) of 175 members attending round 3 seroconverted (figure 2).

Of participants who were seronegative in round 1 and tested in round 3, 55 (5·1%; 95% CI 3·8–6·5) of 1085 participants seroconverted: 19 (5·6%; 3·4–8·6) of 340 students and 36 (4·8%; 3·4–6·6) of 745 staff members (p=0·60; figure 2). In participants who were tested at least twice over the study period (56 of 1511), seroconversion incidence was 1·5 (95% CI 1·1–1·9) per 1000 weeks of follow-up: 1·4 (0·9–2·2) per 1000 weeks for students and 1·5 (1·1–2·1) per 1000 weeks for staff. Among the 56 participants who seroconverted (including one student who seroconverted in round 2 but

	Antibody positive*	Univariable analysis (n=816)		Complete case univariable analysis adjusted for clustering by school (n=714)		Multivariable analysis adjusted for clustering by school (p=1·00; n=714)	
	n/N (%)*	OR (95% CI)	p value†	OR (95% CI)	p value†	OR (95% CI)	p value†
Sex	..	..	0·24	..	0·21	..	0·16
Female	41/415 (9·9%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Male	50/401 (12·5%)	1·30 (0·84–2·01)	..	1·35 (0·84–2·17)	..	1·42 (0·87–2·30)	..
Missing	0	NA	NA	NA	NA	NA	NA
Age, years	..	..	0·039	..	0·049	..	0·14
4–6	27/322 (8·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
7–9	34/220 (15·5%)	2·00 (1·17–3·42)	..	2·03 (1·12–3·68)	..	1·79 (0·98–3·25)	..
≥10	30/274 (10·9%)	1·34 (0·78–2·32)	..	1·18 (0·63–2·19)	..	1·16 (0·63–2·14)	..
Missing	0	NA	NA	NA	NA	NA	NA
Ethnicity	..	..	<0·0001	..	0·0004	..	0·0010
White	37/497 (7·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Mixed or multiple ethnic groups	9/81 (11·1%)	1·55 (0·72–3·36)	..	1·63 (0·73–3·65)	..	1·08 (0·47–2·49)	..
Black or Black British	10/51 (19·6%)	3·03 (1·41–6·54)	..	3·30 (1·41–7·75)	..	2·72 (1·13–6·59)	..
Asian or Asian British	15/101 (14·9%)	2·17 (1·14–4·13)	..	2·26 (1·12–4·56)	..	1·56 (0·76–3·23)	..
Other ethnic group	20/75 (26·7%)	4·52 (2·45–8·33)	..	4·45 (2·22–8·92)	..	4·02 (2·03–7·94)	..
Missing	0/11	NA	NA	NA	NA	NA	NA
Region in England	..	..	0·0002	..	0·0056	..	0·020
Derby	14/154 (9·0%)	0·61 (0·32–1·17)	..	0·64 (0·31–1·34)	..	0·48 (0·23–0·99)	..
East London	23/105 (21·9%)	1·71 (0·96–3·04)	..	1·69 (0·89–3·23)	..	1·48 (0·74–2·97)	..
Manchester	15/192 (7·8%)	0·52 (0·27–0·97)	..	0·65 (0·31–1·35)	..	0·72 (0·35–1·50)	..
North London	37/262 (14·1%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Oxford	2/103 (1·9%)	0·12 (0·03–0·51)	..	0·14 (0·03–0·67)	..	0·22 (0·05–0·97)	..
Attended school during lockdown	..	..	0·40	..	0·53	..	0·13
No	18/126 (14·3%)	1 (ref)		1 (ref)	..	1 (ref)	
Yes	71/613 (11·6%)	0·79 (0·45–1·37)		0·82 (0·45–1·51)	..	0·61 (0·32–1·15)	
Missing	2/77 (2·6%)	NA	NA	NA	NA	NA	NA
Frequency of school attendance during lockdown	..	..	0·52	..	..	..	..
Did not attend	18/126 (14·3%)	1 (ref)		..	..	..	..
≥1 per week	18/192 (9·4%)	0·62 (0·31–1·24)	..	..	..	..	..
Less than half the week	9/96 (9·4%)	0·62 (0·27–1·45)	..	..	..	..	..
More than half the week	18/136 (13·2%)	0·92 (0·45–1·85)	..	..	..	..	..
Everyday	26/189 (13·8%)	0·96 (0·50–1·83)	..	..	..	..	..
Missing	2/77 (2·6%)	NA	NA	..	..	..	..
Previous confirmed COVID-19 in household	..	..	0·007	..	..	..	..
No	84/792 (10·6%)	1 (ref)	..	..	..	..	..
Yes	7/24 (29·2%)	3·47 (1·40–8·61)	..	..	..	..	..
Number of children at home‡	..	..		..		..	
Per one child increase in household	..	1·19 (0·96–1·48)	0·12	1·14 (0·91–1·44)	0·25	1·12 (0·89–1·42)	0·33
Mean (SD) in negative households	2·30 (0·93)	..	..	..	..	..	..
Mean (SD) in positive households	2·48 (1·12)	..	..	..	..	..	..
Parental occupation	..	..	0·0056	..	0·0063	..	0·0046
Not a health-care or key worker	52/555 (9·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Health-care worker	23/115 (20·0%)	2·42 (1·41–4·14)	..	2·58 (1·42–4·68)	..	2·66 (1·44–4·91)	..
Key worker (excluding health-care workers)	16/146 (11·0%)	1·19 (0·66–2·15)	..	1·10 (0·57–2·12)	..	1·01 (0·52–1·98)	..

NA=not applicable. OR=odds ratio. *Unless otherwise specified. †Global p values calculated using the Wald test. ‡60 children had missing data.

***Table 2:* Risk factors for SARS-CoV-2 antibody positivity in students participating in school surveillance during the summer half-term (June to mid-July, 2020)**

was not retested in round 3), 44 (78·6%) completed the final questionnaire; a higher proportion of staff reported COVID-19 symptoms than students (16 [53·3%] of 30 vs two [14·3%] of 14; p=0·021) in the period between testing. In a multivariable Poisson regression, seroconversion was associated with region (p=0·012)

and ethnicity (p=0·0023; appendix p 7). No difference was reported by sex (p=0·33), or between staff and students (p=0·36). Participants in Manchester were significantly more likely to seroconvert than those from North London (incidence rate ratio 2·38; 95% CI 1·24–4·55).

	Antibody positive	Univariable analysis (n=1381)		Complete case univariable analysis adjusted for clustering by school (n=1307)		Multivariable analysis adjusted for clustering by school (p=0·0002; n=1307)	
	n/N (%)	OR (95% CI)	p value*	OR (95% CI)	p value*	OR (95% CI)	p value*
Sex	..	..	0·066	..	0·11	..	0·20
Female	158/1107 (14·3%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Male	51/272 (18·8%)	1·39 (0·98–1·96)	..	1·36 (0·94–1·96)	..	1·28 (0·88–1·87)	..
Missing	0/2	NA	NA	NA	NA	NA	NA
Ethnicity	..	..	0·0004	..	0·0028	..	0·018
White	140/1048 (13·4%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Mixed or multiple ethnic groups	13/49 (26·5%)	2·34 (1·21–4·53)	..	2·32 (1·15–4·67)	..	1·99 (0·98–4·04)	..
Black or Black British	22/71 (31·0%)	2·91 (1·71–4·96)	..	2·78 (1·56–4·94)	..	2·49 (1·38–4·46)	..
Asian or Asian British	26/163 (16·0%)	1·23 (0·78–1·94)	..	1·22 (0·73–2·02)	..	1·16 (0·69–1·95)	..
Other ethnic group	5/31 (16·1%)	1·25 (0·47–3·30)	..	1·43 (0·51–4·02)	..	1·39 (0·49–3·93)	..
Missing	3/19 (15·8%)	NA	NA	NA	NA	NA	NA
Region	..	..	0·0003	..	0·051	..	0·085
Derby	8/133 (6·0%)	0·27 (0·13–0·57)	..	0·26 (0·10–0·69)	..	0·27 (0·10–0·73)	..
East London	84/489 (17·2%)	0·87 (0·62–1·22)	..	0·81 (0·47–1·42)	..	0·70 (0·39–1·24)	..
Manchester	29/257 (11·3%)	0·53 (0·34–0·84)	..	0·55 (0·28–1·09)	..	0·55 (0·28–1·09)	..
North London	83/431 (19·3%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Oxford	5/71 (7·0%)	0·32 (0·12–0·81)	..	0·40 (0·09–1·81)	..	0·48 (0·11–2·14)	..
Attended school during lockdown	..	..	0·048	..	0·21	..	0·20
No	41/203 (20·2%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Yes	164/1116 (14·7%)	0·68 (0·47–1·00)	..	0·77 (0·50–1·16)	..	0·73 (0·48–1·12)	..
Missing	4/62 (6·5%)	NA	NA	NA	NA	NA	NA
Frequency of school attendance during lockdown	..	..	0·14	..	..	..	..
Only home	41/203 (20·2%)	1 (ref)	..	..	..	..	..
Mainly home	66/502 (13·1%)	0·60 (0·39–0·92)	..	..	..	..	..
Equal school and home	53/318 (16·7%)	0·79 (0·50–1·24)	..	..	..	..	..
Mainly school	31/183 (16·9%)	0·81 (0·48–1·35)	..	..	..	..	..
Full time	14/113 (12·4%)	0·56 (0·29–1·08)	..	..	..	..	..
Missing	4/62 (6·5%)	NA	NA	..	..	..	..
Student contact during lockdown	..	..	0·37	..	..	..	..
None	69/385 (17·9%)	1 (ref)	..	..	..	..	..
Occasional	105/698 (15·0%)	0·81 (0·58–1·13)	..	..	..	..	..
Regular	28/198 (14·1%)	0·75 (0·47–1·22)	..	..	..	..	..
Missing	7/100 (7·0%)	NA	NA	..	..	..	..
Other household occupation	..	..	0·0023	..	0·0020	..	0·0069
Not a health-care or key worker	158/1135 (13·9%)	1 (ref)	..	1 (ref)	..	1 (ref)	..
Health-care worker	14/43 (32·6%)	2·99 (1·54–5·77)	..	3·45 (1·69–7·03)	..	3·08 (1·48–6·41)	..
Key worker (excluding health-care workers)	37/203 (18·2%)	1·38 (0·93–2·04)	..	1·35 (0·88–2·06)	..	1·35 (0·88–2·07)	..

NA=not applicable. OR=odds ratio. *Global p values calculated using Wald test.

Table 3: Risk factors for antibody positivity in staff participating in school surveillance during the summer half-term (June to mid-July, 2020)
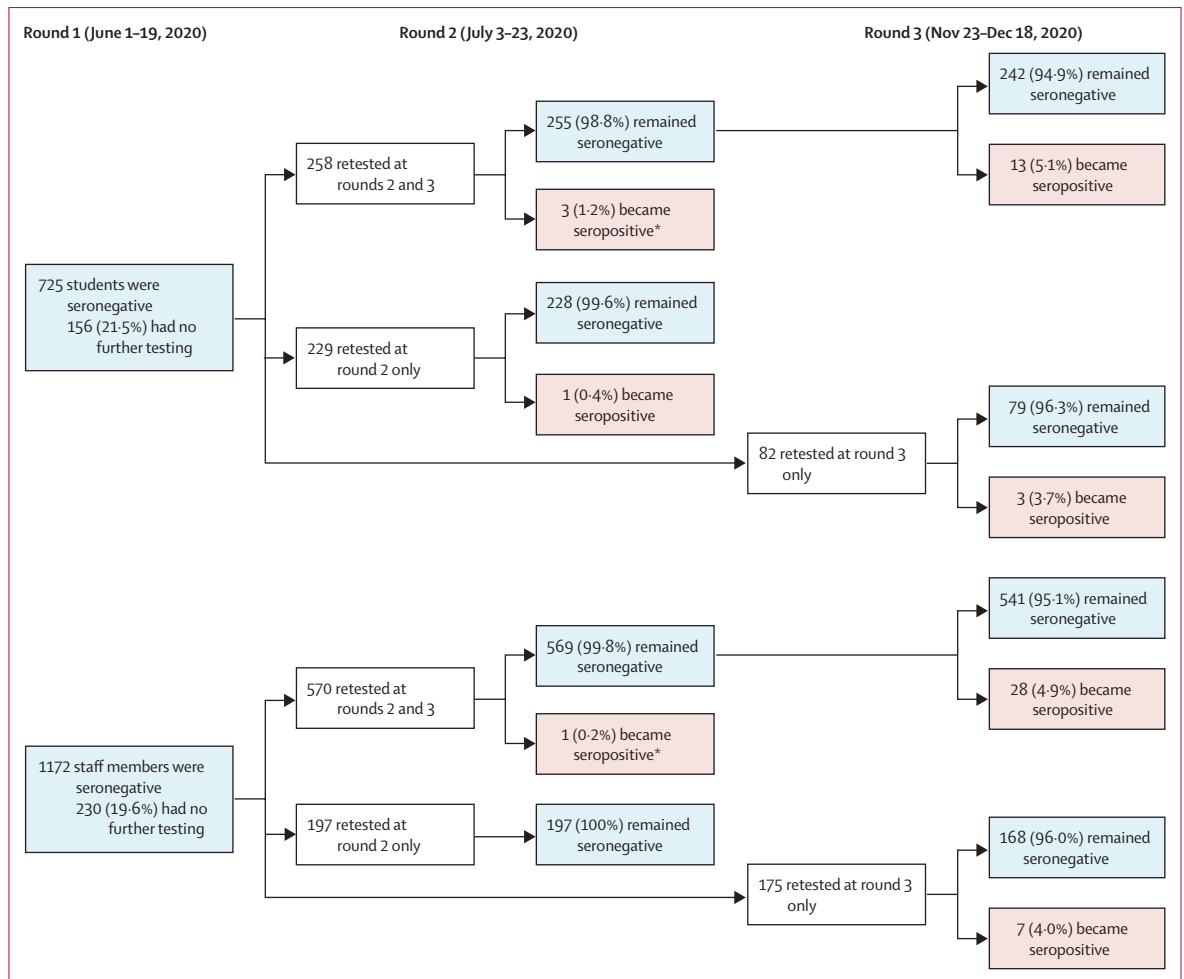
Figure 2: Flow chart of SARS-CoV-2 antibody results in students and staff who were seronegative at recruitment
*These participants were tested again in round 3.

Discussion

Active, prospective surveillance identified very low rates of SARS-CoV-2 infection in primary schools during the summer half-term in England, when schools reopened only for certain year groups. Only three of 40 501 swabs from 11 966 participants in 131 schools had confirmed SARS-CoV-2 infection. At recruitment, SARS-CoV-2 seropositivity was 11·2% in students and 15·1% in staff, similar to local community seroprevalence. We found no significant association between antibody positivity and school attendance during lockdown. The degree of staff contact with students (regular, occasional, or none) was also not associated with seropositivity. There were only five seroconversions among staff and students during the summer half-term. SARS-CoV-2 infection and seroconversion rates in staff and students remained at or below 5% even after primary schools reopened fully during the autumn term.

In England, some primary schools reopened in June, 2020, when community SARS-CoV-2 infection

rates were generally low nationally. Because of concerns about asymptomatic infections and silent transmission in schools, we rapidly initiated SARS-CoV-2 surveillance and successfully recruited large numbers of students and staff in primary schools across all English regions. Large-scale weekly mass testing identified only three people with SARS-CoV-2 infections, whereas three others with an initial positive swab (with very high cycle threshold values), which were then repeat tested as negative following concentration, showed that false positivity does exist, but procedures are in place within the laboratory to investigate these aberrant results. Further evidence of no antibody development 4–6 weeks later shows that the results of retesting were correct.[22]

Despite the challenges of blood sampling large numbers of staff and students, we used serum SARS-CoV-2 antibodies to assess previous infection because this method would also capture asymptomatic and mild, transient infections. At recruitment, seropositivity rates in students and staff were similar and reflected

local community seroprevalence. This finding is important because children represent less than 5% of confirmed COVID-19 cases,[23,24] and the similar seropositivity rates in students and staff indicate that children are as likely to be infected with SARS-CoV-2 as adults, but more likely to develop asymptomatic or mild, transient illness, which would also reduce their likelihood of getting tested for SARS-CoV-2 infection. The higher seropositivity in minority ethnic groups is consistent with published literature,[25] although to our knowledge this is the first report in children. A higher risk of SARS-CoV-2 infection in students and staff living with a health-care worker is unsurprising since they were more likely to be infected with SARS-CoV-2,[26] and develop COVID-19,[27] especially early in the UK epidemic when personal protective equipment in health-care settings was limited.

Seropositivity rates in staff were similar to community seroprevalence at recruitment, indicating that they were not at higher risk of infection than people in other professions.[26] In our cohort, both staff and students who did not attend school during lockdown had higher albeit non-significant seropositivity rates than those who attended school, possibly because of increased exposure to household members at high risk of COVID-19, more opportunities for infection in the community than in school (because of small numbers of students and staff attending during lockdown, with strict infection control practices in place), or both. A systematic review, for example, found infection risk from household contacts to be ten times higher than contacts from any other setting.[28] Additionally, at recruitment, there was significant clustering of seropositive cases by school in staff but not in students. This could be due to increased transmission risk between staff in school but could also reflect the local community seroprevalence rates in adults at the time.

There are few other similar serosurveillance studies for comparison, but in Sweden, which kept preschools and primary schools open during lockdown, repeated serosurveys among primary care patients without COVID-19 showed similar seropositivity rates in individuals younger than 20 years and working-age adults during April–May, 2020.[1,29] In England, a national cross-sectional survey of 105 schools found less than 1% SARS-CoV-2 infection rates in primary school students and staff attending school during November, 2020.[30] Low infection, seroconversion, and outbreak rates in primary schools[15] contrast with other institutional settings, such as care homes, where widespread asymptomatic infection and silent transmission were common even before an outbreak was recognised. In London care homes reporting a COVID-19 outbreak, for example, half of the residents and 20% of staff were SARS-CoV-2 RT-qPCR positive when tested and half of them never developed symptoms.[31] Additionally, two-thirds of asymptomatic and RT-qPCR-negative residents and staff had SARS-CoV-2 antibodies at the end of the outbreak.[32] Reassuringly, 96–100% of RT-qPCR-positive residents and staff developed SARS-CoV-2 antibodies irrespective of whether they were symptomatic or asymptomatic, highlighting the added value of antibody testing to measure the spread of infection in institutional settings.[32]

The autumn term saw all children returning to school, making physical distancing and other infection control measures difficult to implement. In primary schools, staff and students were not required to wear face masks or face coverings.[13] In England, SARS-CoV-2 infection rates are reported weekly for all age-groups,[33] but the national reports only include testing of symptomatic cases and thus do not provide any insight into asymptomatic infections or silent transmissions. We used the Abbott assay, which detects nucleoprotein antibodies within 7–14 days after infection; it is quicker than other assays, such as those measuring spike protein antibodies, and would therefore detect seroconversion quickly between antibody testing rounds.[20] The low seroconversion rates during the autumn term, in addition to the negligible seroconversions during the summer half-term, provides further reassurance against high rates of asymptomatic infections among students or silent transmission to staff in primary schools. The emergence and rapid spread of a novel SARS-CoV-2 variant of concern (VUI-202012/01; VOC B.1.1.7) since December, 2020, which is more transmissible than previously circulating strains, will require careful monitoring now that schools have reopened (on March 8, 2021) after the latest national lockdown.[34]

The strength of this surveillance study is the large numbers of schools and participants recruited rapidly when schools reopened from June, 2020, highlighting the willingness of parents to allow their children to take part in school surveillance. The low infection and seroconversion rates during the summer half-term helped to support the full reopening primary schools during the autumn term. A limitation of the study was that the participating schools were not selected to be nationally representative. In particular, the schools in the blood sampling group were recruited in regions where we had paediatric teams to collect blood samples. We also did not collect samples at the start of the lockdown and therefore cannot comment on whether seropositive participants might have been exposed to SARS-CoV-2 in school or the community before lockdown. Moreover, the study was open to all staff and students, but the characteristics of those who took part might be different to those who declined. Additionally, not all participants returned for rounds 2 and 3 and, because of differences in returns among seropositive and seronegative participants, the seroprevalence rates during subsequent visits should be interpreted with caution. The retention of seronegative participants, however, provided a useful baseline for estimating seroconversion during the summer and autumn terms. Finally, our findings cannot be extrapolated to senior schools,[2] because older children have a higher risk of infection and disease than younger

children,[35,36] with higher propensity for SARS-CoV-2 transmission and outbreaks in secondary compared with primary schools.[37,38]

We found a very low risk of SARS-CoV-2 infection in students or staff attending primary schools during both partial reopening in the summer half-term and full opening in the autumn term. The similar seropositivity rates indicate that students are as likely to get infected as staff but more likely to have asymptomatic or mild illness. Similar studies are needed in secondary schools and higher-education settings, in which the risk of infection, transmission, and disease are likely to be different.

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