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Evidence summary of potential for children to contribute to transmission of SARS-CoV-2

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Key points

- Adults and children of any age can be infected with SARS-CoV-2 (the virus that causes COVID-19); however, to date reported cases of COVID-19 in children account for a small percentage of diagnosed cases. The role that children play in the transmission of the SARS-CoV-2 virus is unclear. This evidence summary includes studies on transmission of SARS-CoV-2 by children to others (child or adult) and does not address the risk of infection to children or their disease severity.
- In total, 28 studies were identified. Nineteen investigated household and close contact transmission, six examined transmission of SARS-CoV-2 in schools and three were modelling studies estimating age-specific transmissibility of SARS-CoV-2.
- Ten of the 19 studies on household and close contact transmission reported child-to-adult or child-to-child transmission, although at very low rates. There were concerns over the accuracy of the reporting in some studies, and it is possible that transmission events might have been missed and errors made in ascertaining the direction of transmission.
- Three of the six studies assessing transmission within educational settings (schools and pre-schools), reported transmission from children while three reported no transmission.
    - Three studies (from Ireland, Finland and Singapore) analysed the spread of SARS-CoV-2 from a total of nine confirmed cases (five students and four staff) across eight educational settings. From 1,036 close contacts, no confirmed transmission from a child was reported.
    - Three studies (from Australia, South Korea and Israel) analysed the spread of SARS-CoV-2 from a total of 74 confirmed cases (59 students and 15 staff) across 66 education facilitates to over 13,000 close contacts. In total, 198 (183 linked to student cases and 15 linked to staff cases) additional cases associated with initial cases at their educational settings were reported. Of the 198 cases, 178 were from one study in Israel, the applicability of which is uncertain given concerns about adherence to precautionary measures such as physical distancing and mask wearing. Household or community transmission also cannot be ruled out for these cases.

- While all three mathematical modelling studies estimated that children were less likely to infect others than adults, there were concerns regarding the quality of these studies.
- Large scale studies focusing on transmission chains using data collected from contact tracing and serological studies looking for past evidence of infection are needed to determine how children are contributing to the spread of SARS-CoV-2.
- From the studies identified, based on low certainty evidence, transmission from child-to-adult or child-to-child does occur in household and educational settings, but reported transmission rates for children remain low. Few definitive cases of virus transmission from children have been published to date with no clear evidence to support a higher rate of transmission for children than adults.

Introduction

The Health Information and Quality Authority (HIQA) has developed a series of 'Evidence Summaries' to assist the Clinical Expert Advisory Group (EAG) in supporting the National Public Health Emergency Team (NPHET) in its response to COVID-19. These summaries are based on specific research questions. This evidence summary was developed to address the following research question:

> **What evidence is available to indicate that children spread SARS-CoV-2?**

The processes as outlined in HIQA's protocol were followed (available at www.hiqa.ie). This summary was first published in April 2020 and has been updated to reflect newly available evidence up to 10 August 2020.

Results

Thirteen studies were included from the original search and previous updates (up to 31 May 2020). Fifteen further studies were identified in this update, giving a total of 28 studies considered relevant for inclusion (Table 1). These comprised 19 studies of reported household and close contact transmission,[1-19] six reports on transmission of SARS-CoV-2 in schools settings[20-25] and three modelling studies estimating age-specific transmissibility of SARS-CoV-2.[26-28] Six studies were from China,[1, 2, 6, 7, 9, 26] three each from the USA,[11, 13, 16] and Israel,[17, 23, 27] two from South Korea,[12, 24] and one report each was from Ireland,[21] Switzerland,[8] Australia,[22] France,[3] Italy,[4] Vietnam,[5] Singapore,[29] The Netherlands,[18] Thailand,[10] Morocco,[14] Finland,[20] India,[15] and New Zealand.[28] A secondary data analysis paper included data from China, Singapore, South Korea, Japan, and Iran.[19] Sample sizes for included child cases ranged from 1 to 74, and where reported, contact numbers ranged from 3 to 597 in household and close contact transmission studies[3, 8-11] and from 119 to over 10,000 in school-based studies.[20-25]

Household and close contact transmission

Nineteen studies examined household and close contact transmission. There were three analyses of surveillance data,[11, 15, 18] eight case series,[1-3, 8, 10, 16, 17, 19] seven case reports,[4-7, 12-14] and one analysis of local heath commissions' public disclosures in China.[9]

Two of the three studies examining surveillance data documented transmission from children.[15, 18] An analysis of 732 infector and infectee pairs from data on reported cases from the Dutch National Institute for Public Health and the Environment (RIVM) noted that COVID-19 was primarily spread between persons of approximately the same age.[18] In those aged under 20, there were 31 cases identified, 23 of which were infected in the home. Two of these 23, occurred

between peers (child-to-child spread), although the source in one of these cases was aged between 15 and 20 years. For the remaining 21 cases the source of infection was aged between 21 and 46 years (most likely parent-to-child). Most of the results come from a period when the schools were closed. In a large study based on public health surveillance data of 4,206 confirmed cases and 64,031 contacts in India, 288 children (aged 0-17 years) with 2,107 contacts were included.[15] From the child index cases, 7% of child contacts and 12% of adult contacts tested SARS-CoV-2 positive. Contact tracing data was, however, only available for 12.5% of all cases identified which may overestimate the effect exposures within the household. Data were also missing on the timing of exposure and symptom onset.[15]

The third surveillance study described an outbreak of SARS-CoV-2 at an overnight camp in the state of Georgia in the US that was detected after a teenage staff member (age not reported) tested positive for SARS-CoV-2.[11] All attendees were tested, and cases linked to the camp were defined as a positive viral RNA test from when they first arrived until 14 days after they left. In total, test results for 344 of 597 Georgia residents were available, with 76% (260/344) positive. The camp required documentation of a negative SARS-CoV-2 test ≤12 days before arriving. Masks were required to be worn by staff members, but were not required for campers. Campers stayed in cabins (mean 15 per cabin), but windows and doors were not open. Camp attendees engaged in a variety of indoor and outdoor activities, including daily singing and cheering. While these findings demonstrate that SARS-CoV-2 prevalence was high in this predominantly young cohort, given the increasing incidence of COVID-19 in Georgia at the time, household or community transmission cannot be ruled out for these cases.

Transmission from a child was confirmed or suspected in five of the eight case series identified. The case series by Cai et al.[1] confirmed transmission of SARS-CoV-2 from one of the 10 included children to two family members. This transmission was from a three month old infant to both parents, who developed symptomatic COVID-19 seven days after taking care of the infant.[1] A case report of this infant confirms that, at the time of diagnosis, both parents had negative SARS-CoV-2 real time polymerase chain reaction (RT-PCR) results.[30] A secondary analysis of data study reported 31 SARS-CoV-2 household transmission clusters, of which 9.7% (3/31) were identified as having a paediatric index case.[19] The original papers for two of these cases could not be retrieved during this current review update, while the third case was of the infant described in the case series by Cai et al..[1] The authors conducted an analysis of the data assuming that asymptomatic children are being mistakenly overlooked as the index case in familial clusters. Using this approach (assuming asymptomatic children as the index case), 21% (6/28) of family clusters would have a paediatric index case.[19] A case series describing the dynamics of infection in the families of 39 children (<16 years old) with COVID-19 in Switzerland

found a similar pattern, reporting that in 8% of cases (3/39) a child developed symptoms prior to any other household contact.[8] However, household contacts were asked to self-report whether they developed symptoms before, after or at the same time as the child case. The time to symptom onset or diagnosis was not reported with the authors noting that they could not confirm that child-to-adult transmission definitively occurred given the study design.

In an investigation of clusters of infections within 13 families living in Bnei Brak, Israel, the first case of the infection in the family was reported by parents to be a child in one cluster (8%).[17] This was a case of a 14-year-old male who was exposed at the Yeshiva (Jewish educational institution). It is unclear how many family members were subsequently infected. In a case series of COVID-19 patients aged 0-17 years in Chicago in the United States (US), data necessary to determine transmission were available for 15 households of which 11 (73%) were adult-to-child, two (13%) were child-to-child, and two (13%) were child-to-adult.[16] Within a household, transmission was determined to be child-to-adult or child-to-child, based on reported onset date of symptoms.

Three cases series reported no transmission from children. A case series describing the epidemiological and clinical characteristics of 74 children with COVID-19 admitted to two hospitals in China reported no evidence that the virus was transmitted from these 74 children to others, although there is limited reporting of how this information was ascertained in the manuscript.[2] Exposure data were available for 68 of the 74 patients with 65 (96%) of these cases being household contacts of adults whose symptoms developed earlier.

In a case series of three paediatric COVID-19 cases in Thailand, all children were placed in isolation in a hospital with adult care givers.[10] One case was isolated with his grandfather who was also infected with COVID-19, while two cases were isolated with their healthy caregivers. During isolation, children and their caregivers were advised to wash hands frequently and not share personal items. Surgical masks were provided, but compliance was observed to be poor. Both healthy care givers tested SARS-CoV-2 negative based on PCR tests of nasopharyngeal and throat swabs for the duration of the isolation, with no symptoms in the caregivers up to 14 days post discharge.

Danis et al.[3] investigated a cluster of COVID-19 cases in the French Alps, linked to one single adult index case. Eleven contacts of this index case tested positive for SARS-CoV-2 (RT-PCR of upper or lower respiratory sample), of which one was a nine year old child, co-infected with other respiratory viruses (picornavirus and influenza A). While symptomatic, the child visited three schools (duration of visit was not reported) and attended one ski class. Overall, 172 contacts were identified of which 112 were school contacts. Of these, 169 individuals were contacted, 70 (41%) had

respiratory symptoms during the investigation and a total of 73 were tested with one additional case (linked to an adult case) of COVID-19 identified.

Five of the seven case reports found no transmission of SARS-CoV-2.[4, 5, 7, 13, 14] In three case reports, no transmission from SARS-CoV-2 positive children being cared for by their mothers was reported.[5, 7, 14] Use of precautions such as face masks were described in two of these studies.[5, 14] In two case reports, no transmission from a SARS-CoV-2 positive children to medical staff was documented.[4, 13] Details on personal protective equipment (PPE) and other precautions used by medical staff were not reported in one study.[4] Two case reports reported transmission of SARS-CoV-2 by children.[6, 12] A COVID-19 outbreak in a paediatric ward in South Korea, was concluded to be a case of transmission from a child to an adult.[12] A nine-year-old girl was admitted to hospital with a one-day history of headache. The initial PCR result from a nasopharyngeal swab was negative. Shortly afterwards, the hospital was notified of an outbreak and all recent inpatients were tested. The patient's second SARS-CoV-2 PCR results were positive. From contact tracing 1,206 close and casual contacts were identified and 1,152 underwent testing. The results were negative for all but one of the contacts, including the index patient's parents and health care workers. A 40-year-old mother (patient B) of a hospitalised infant (PCR-negative for SARS-CoV-2) who shared the six-patient room directly (approximately 3m) across from the index patient tested positive. Patient B had been discharged before the index patient was diagnosed with COVID-19, so it is plausible that the source of infection was household or community transmission and not the 9-year-old girl.

Lin et al.[6] in a case report of a COVID-19 positive seven year old girl, concluded that the girl infected her father. However, the day before meeting his daughter, the father drove and took a bus to Xiangyang, Hubei province where he stayed overnight. Given this exposure to the epidemic area, coupled with inconsistencies of reporting of dates within the manuscript, it is also plausible that the father was the source of infection.

The analysis of Chinese public disclosures data[9] based on 419 index patients and their 595 household secondary infections, reported no cases of infection by an index patient 15 years of age or younger. Data presented suggests that three of the index patients were aged less than 18 years and were linked with three secondary cases; however, there are some concerns over the accuracy in the presentation of these data. In a linked publication, the authors estimate that the hazard of being infected within households was higher for those aged under 18 and those over 65 years, whereas the hazard of being infected outside of households was higher for those aged 18 to 64 years.[31]

School-based transmission

Three out of six studies in school settings reported transmission of SARS-CoV-2 by children. A study from New South Wales (NSW), Australia examined SARS-CoV-2 transmission among children and adults in 25 educational settings (15 primary and secondary schools, and 10 early childhood education and care settings [ECEC]) over a three-month period.[22] NSW kept schools open during the pandemic with guidance for physical distancing, hygiene measures, and educational facility cleaning with distance (online) learning at the epidemic peak (March 23). They identified 27 confirmed cases (12 children and 15 staff) who attended school or ECEC settings while considered infectious (defined as 24 h before symptom onset), and 1,448 close contacts (1,185 students and 263 staff). A close contact was defined as a person who had been in face-to-face contact for at least 15 minutes or who shared a closed indoor space for at least 40 minutes (generally the same class or lesson, typically consisting of 20–30 students) with a case during their infectious period. In total, 633 of 1,448 close contacts had nucleic acid testing, or antibody testing, with 18 secondary cases (10 children; eight adults) identified across all settings. These comprised five secondary cases (three children; two adults) identified in three schools and one outbreak in an ECEC setting that involved transmission to six adults and seven children. The overall child-to-child transmission rate was 0.3%, and the attack rate for child to staff member was 1.0%. The rate of staff member to child transmission was lower (1.5%) than staff to staff transmission (4.4%).

An analysis of data on 45 paediatric patients with COVID-19 collected from press releases by the Korean Centers for Disease Control and Prevention examined transmission in 40 schools and kindergartens, and 10,903 contacts.[24] There was only one elementary school where secondary cases were observed; one 11 year old transmitted the virus to two other children. One child was infected in the same classroom, and the other was not in the same class, but was infected at the same gym out of school. In Israel, a large outbreak was reported 10 days after schools reopened.[23] Following diagnosis of two unrelated cases, the full school community (151 staff, 1,161 students) was tested; 178 (25 staff, 153 students) tested positive for SARS-CoV-2. During this time, there was an extreme heat wave, with school attendees exempt from mask wearing and the air conditioning continuously on. Class rooms were also reported to be overcrowded and physical distancing could not be observed. Furthermore, household or community transmission cannot be ruled out for these cases.

The remaining three studies reported no transmission of SARS-CoV-2 by children. An analysis of Irish notifications of SARS-CoV-2 in the school setting found no transmission from children.[21] All notifications occurred in early March, before universal school closure on 12 March 2020. Prior to this closure, when a case was identified within a school, either all children and staff within the school or all children

and staff involved with an individual case were excluded, limiting the potential for further transmission. Three paediatric cases (all aged between 10 and 15 years) and three adult cases of COVID-19 with a history of school attendance were identified, along with 1,155 contacts (1,025 school contacts, 130 other settings). None of the six cases were infected with SARS-CoV-2 via the school setting. Five of the six cases had symptoms of either cough or fever. Contacts were exposed at school in the classroom, during sports lessons, music lessons and during choir practice for a religious ceremony, which involved a number of schools mixing in a church environment, although the length of time of these activities is not reported. The three paediatric cases had a total of 822 child contacts and 83 adult contacts within the school setting. No additional cases were identified during the follow-up period (14 days) from last contact with the index case. However, only contacts who developed symptoms were referred for testing, thus asymptomatic secondary cases were not captured. Transmission was observed in one instance outside the school environment, between two adult cases and a further adult.

Similarly, a report of SARS-CoV-2 transmission among children in two preschools and one secondary school in Singapore found no transmission from children.[29] At the time, schools were not routinely closed, but targeted public health measures including terminal cleaning of the schools and measures to reduce student mixing, such as suspension of extracurricular or sport activities and staggered recess breaks were implemented. Two paediatric cases (a 12-year-old secondary school student and a five-year-old pre-schooler) and one adult case of COVID-19 with a history of school attendance were identified, along with 119 contacts. Both students attended their educational settings on the first day of their symptoms before subsequently being diagnosed with COVID-19 and isolated in hospital. In the secondary school setting, a total of eight students developed symptoms and were screened for SARS-CoV-2 during the incubation period, all testing negative. In the preschool setting, a total of 34 preschool student contacts developed symptoms post exposure and were tested for SARS-CoV-2 but all were found to be negative. In a separate preschool, an adult staff member tested positive with a total of 16 adult staff members additionally becoming infected. In follow up of 77 children from the preschool (about 73% of the total preschool student population), eight reported symptoms consistent with COVID-19 but no child tested positive for SARS-CoV-2.[29]

A report of SARS-CoV-2 transmission among children in two schools in Finland also found no transmission from children.[20] Exposure in school due to a 12-year-old index case who attended with mild symptoms led to no further cases among 121 close contacts. Close contacts included pupils who attended the same classes or shared the same lobby, teachers of the respective classes and other school personnel in close contact (< two metres, for at least 15 minutes) with the index case, and sports team contacts who attended practice and coaches who were in

close contact with the index case. In a separate school, contacts of an adult index case with moderate symptoms were followed up more than 28 days after exposure. Antibodies were detected in eight (seven children and one adult) out of 63 close contacts. Based on follow up of these seven paediatric cases, an additional five cases were identified among 29 contacts. However, given the time frame, household or community transmission cannot be ruled out for these cases.

Transmission modelling

All three modelling studies estimated lower transmission in children.[26-28] In a mathematical modelling study estimating age-specific transmissibility of SARS-CoV-2, Zhao et al.[26] concluded that SARS-CoV-2 had high transmissibility among adults aged 25 years or older, but low transmissibility among children or people younger than 14 years. The model fit was compared to data from 29 cases (10 of whom had exposure to the Huanan seafood market); this is a very small sample to check the fit of a model. Furthermore, those with exposure to the seafood market may not be representative of transmission patterns more generally. Dattner et al.[27] fitted a dynamic stochastic age-of-infection model to estimate household SARS-CoV-2 transmission in Bnei Brak, Israel. Data were collected from 637 households (3,353 people) of at least two members, with all household members tested and at least one with PCR-confirmed COVID-19. Transmission was estimated to be lower in children (aged 0-19 years), compared with adults (aged 20+), although this difference was not statistically significant (HR: 85%; 95% CI 65-110). James et al.,[28] analysed the transmission dynamics of COVID-19 using a comprehensive dataset for a completed outbreak (at the time) in New Zealand. They estimated that although children under 10 years were equally likely to infect at least one person, they contributed less to the spread of COVID-19 than other age groups, infecting fewer people on average and having a lower secondary attack rate. Across all three studies, there were very few child index cases.[26-28]

Study quality

The 19 primary studies reporting on household and close contact transmission were of low to moderate quality for their designs, as there was a lack of detail as to how cases were selected, what the criteria for testing contacts was, what testing was undertaken and how consistently testing was conducted across all contacts.[1-9, 17, 21, 22] Three studies had small sample sizes (less than 10),[1, 3, 10] seven studies were case reports.[4-7, 12-14] Three studies were pre-prints and had not undergone formal peer review at the time of writing.[9, 15, 19] The secondary analysis of data focused on household transmission clusters from published literature and publicly available data was also a preprint.[19] Two studies used existing public data,[9, 19] meaning there is potential for double counting of cases across studies. In household studies, transmission was often assessed by self-report by households as to which family member developed symptoms first,[8, 16, 17] and length of follow up was not consistently reported across studies. While household studies provide a unique opportunity to study transmission in a clearly identified cohort of close contacts, it is

still possible that transmission events might be missed and errors in ascertaining the direction of transmission may be made.

All six studies in school settings had small numbers of child cases, but followed up a large number of contacts.[20-25] Symptomatic contacts were followed up for 14 days in the study by Heavey et al..[21] In Macartney et al.,[22] the majority of contacts were tested after symptoms developed. Given potential transmission from asymptomatic or mild contacts,[32, 33] the potential for missing cases cannot be ruled out. Two studies were pre-prints.[20, 24] In all of these studies, household or community transmission cannot be ruled out for positive cases detected.[22-24]

All three modelling studies were pre-prints, from non peer-reviewed journals and used household data collected when countries were in various forms of lockdown.[26-28] Across all three there were very few child index cases.[26-28] The modelling study by Zhao et al.[26] had a very small sample to check the fit of a model and the sample from the seafood market may not be representative of transmission patterns more generally. Data for the model by Dattner et al.[27] did not include dates of infection or information about who the index patient was. The study only used aggregate numbers of infected individuals in the two age groups and the majority of the data used were from households with a size of two. In James et al.[28] data on missing cases and missing transmission routes were estimated using Monte Carlo methods.

Discussion

Adults and children of any age can be infected with SARS-CoV-2; however, to date, reported cases of COVID-19 in paediatric populations account for a small percentage of all diagnosed cases. The European Centre for Disease Prevention and Control (ECDC) report that as of 26 July 2020, children (aged less than 18 years) accounted for 31,380 of the 744,448 (4%) of cases reported to The European Surveillance System (TESSy).[34] In the United States, data from Centers for Disease Control and Prevention (CDC) indicates that 7% of diagnosed COVID-19 cases are in children under 18 years of age.[35] Provisional data from the Health Protection Surveillance Centre demonstrate in Ireland with 2.4% of 26,837 confirmed cases, as of 13 August, aged less than 15 years.[36] Paediatric SARS-CoV-2 is often milder than that in adults and a large proportion are likely to be asymptomatic.[32, 33] Given initial test capacity constraints, there was an international trend towards restricting or prioritising RT-PCR testing to designated groups such as healthcare workers and or those with a greater disease burden. As a function of this, fewer cases may have been diagnosed in children leading to a potentially higher relative underreporting. Emerging data from serological studies in European countries looking for evidence of past infection, indicate that children and adolescents have slightly lower levels of previous infection (antibodies) than adults.[34] However, is it not known if this lower prevalence reflects lower

susceptibility to infection or lower exposure in the early stages of the pandemic due to social distancing measures. There are conflicting reports as to whether children are less susceptible to SARS-CoV-2 infection. A systematic review (pre-print published 24 May 2020) of 18 studies reported preliminary evidence that children and young people have lower susceptibility to SARS-CoV-2, with a 56% lower odds of being an infected contact within studies of contact-tracing.[37] A mathematical model study using data from six countries estimated that susceptibility to infection in individuals under 20 years of age was approximately half that of adults aged over 20 years.[38] They argued that low case rates in children could also be explained by age-specific severity, (that is, children are more likely to be asymptomatic and experience milder symptoms).[38]

Reported transmission

The emerging evidence in this review highlights that child-to child and child-to adult transmission of SARS-CoV-2 may occur. However, unlike other viral epidemics like influenza,[39] children currently do not appear to be key transmitters of SARS-CoV-2, with reported transmission from children remaining low. The majority of included studies have looked at household transmission in known cases and it is often unclear in the literature who the index patient is. Six studies examined transmission of SARS-CoV-2 in schools. These results are consistent with similar previous reviews in the area.[40, 41]

Ten of the 19 included studies on household and close contact transmission reported child-to-child or child-to-adult transmission. Four household transmission studies showed that children were the index case in 8 to 26% of households.[8, 16, 17, 19] However, it is difficult to ascertain from the broader literature who exactly was the index patient. In their secondary analysis of existing data, Zhu et al.[19] reported that assuming asymptomatic children were the index case in all familial clusters would still produce a situation where children only accounted for a limited percentage (21%) of household cluster transmissions. All three studies examining large scale surveillance data reported transmission from children at varying levels.[11, 15, 18] Two of these studies highlight that COVID-19 is primarily spread between persons of approximately the same age and the probability for contacts to have a positive test result is not clearly associated with their age.[18] Across the remaining case series and case reports, transmission was variable with a lack of information and inconsistencies of reporting within the manuscripts. One of the largest case series of 74 children with COVID-19 reported no evidence that the virus was transmitted from children to others. In at least three studies that suggested transmission from children to other family members occurred,[1, 6, 12] it is also feasible that the virus transmitted from the parents or adults to the children. To date, published studies indicate that children are mostly infected by family members in the home.[42-46]

Many SARS-CoV-2 clusters have been linked to a wide range of mostly indoor settings such as households and few reports came from schools.[47] This is perhaps unsurprising as many of the included studies were conducted in the context of strict social distancing policies including school closures. Analysis of social contact and age-mixing patterns in China during the outbreak period, where strict social distancing policies were in place, highlights that typical features of age-mixing (school contacts, workplace contacts and so on) decreased and contacts during the outbreak mostly occurred at home with household members.[48, 49] Studies of household transmission which describe presumed contact and transmission, but did not specifically report transmission from child to adult[50]or the age of the index cases[51] were not included in this review.

Three included case reports[4, 12, 13] reported no transmission from children to healthcare workers. One study described the use PPE consisting of N95 mask, face shield, gowns, and gloves,[13] but the other studies did not provide any details. The risk of occupational exposure to SARS-CoV-2 may be lower in paediatric settings, due to a lower number of COVID-19 patients admitted in this setting, and to higher awareness and compliance with protective measures.[52]

Following a survey of the experience of 15 European countries related to the role of childcare and school settings in COVID-19 transmission and a review of the literature, the ECDC reported few significant outbreaks of COVID-19 in schools.[34] The results of this current review, which include one additional new study and one updated study with additional data beyond the ECDC report, are in keeping with these findings. Of the six studies on transmission of SARS-CoV-2 in schools included in our review, three (from Australia, South Korea and Israel) reported transmission occurred within schools. Across the three studies, a total of 74 confirmed cases (59 students and 15 staff) across 66 education facilitates and over 13,000 close contacts were included. In total, 198 (183 linked to student cases and 15 linked to staff cases) additional cases associated with these initial cases at their educational settings were reported. The majority of these cases (178/198) were identified in one study from Israel,[23] where precautionary measures, such as mask wearing and physical distancing, were not observed and where household or community transmission cannot be ruled out for these cases.

A rapid systematic review (published 1 May 2020) on school closure during coronavirus outbreaks (including COVID-19) found limited and conflicting information.[53] The authors cite recent modelling studies of COVID-19 which predict that school closures alone would prevent 2% to 4% of deaths, much less than other social distancing interventions.[53] Subsequent modelling studies also report that school closures alone have limited impact on reducing the burden of COVID-19.[54, 55]

All three modelling studies estimated lower transmission in children; however, there were very few child index cases included across studies.[26-28]

Transmission potential

Although studies of real-life transmission in school settings remain limited, transmission potential of SARS-CoV-2 by children is influenced by a number of factors other than susceptibility to infection including potential for exposure to the virus and viral load (the amount of virus that a child might carry). In relation to exposure to the virus outside of the home, six studies looking for evidence of past infection in childcare and school settings were identified (described in more detail in Table 2). While these studies do not present evidence on actual transmission chains from infected children to others, they do characterise the burden of COVID-19 within these settings during the epidemic period. Across five studies, seroprevalance, or the prevalence of antibodies indicative of a previous infection, ranged from 0.7% to 39% for pupils, and 0.2% to 43% for teachers.[57-61] A study in Belgian daycare settings, undertaken shortly after the start of the epidemic and before lockdown commenced, noted that while cold symptoms were common, RT-PCR tests of nasopharyngeal specimens taken from a random sample of children (n=84) attending eight different daycare centres were all negative for SARS-CoV-2.[62]

We have conducted a separate review of viral load and infectivity over course of infection. A limited number of studies have been published to-date comparing viral loads between and adult and paediatric populations. While no discernible differences with regards to viral load or duration of virus detection between adults and children were reported, there are concerns regarding the statistical analysis undertaken in some of the included studies.[63] However, emerging evidence may suggest age-related differences in SARS-CoV-2 levels in patients with mild to moderate COVID-19.[64] The relationship between viral load and infectivity is not well understood as viral load is only a proxy measurement of infectivity and may not translate to transmissibility. The HIQA review found evidence of prolonged viral shedding in stool samples, particularly in children. While potentially a source of faecal-oral transmission, the clinical significance of this finding is uncertain.[65] Separately, an investigation on environmental contamination in an isolation room of an infected infant was identified that reported that a generally well infant with COVID-19 can contaminate the environment with PCR-detectable virus.[29] However, reliable, large scale data on transmission from symptomatic and asymptomatic children is lacking.

Future research

Large scale studies focusing on transmission chains using data collected from contact tracing and case investigations are needed to determine how children are contributing to the spread of SARS-CoV-2. As schools and childcare facilities gradually re-open internationally, more data on transmission chains linked to

children outside of the household setting may become available. Serological studies looking for past evidence of infection, and studies assessing viral load in infected children and the relationship between viral load and transmission may also be helpful in understanding the role children play in transmission.[66]

Conclusion

There is currently limited information on the contribution of children to the transmission of SARS-CoV-2. Few definitive cases of virus transmission from children have been published to date with no clear evidence to support a higher rate of transmission for children than adults. From the published studies identified, it appears that children are not, to date, substantially contributing to the household transmission of SARS-CoV-2. From six school-based studies investigating transmission of SARS-CoV-2 in children, it appears that rates in this setting are also low.

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Table 1 Characteristics of included studies

Author Country Study design	Population setting Patient demographics Clinical characteristics	Primary outcome results
Household and close contact transmission		
Cai[1] **China (Shanghai)** **Case Series** **DOI:** 10.1093/cid/ciaa198	**Population setting:** 10 patients admitted to a Children's Hospital for screening based on presenting with acute fever and/or respiratory symptoms AND an epidemiological link to an adult case/exposure to an epidemic area. **Demographics:** *Age:* 3-131 months (mean: 74 months) *Gender:* Male n = 4, female n = 6 **Clinical characteristics:** *Presentation:* Fever n=8 (80%); cough n=6 (60%); sore throat n=4 (40%); stuffy nose n=3 (30%); sneezing and rhinorrhoea n=2 (20%). RNA positive within 4-48 hours after symptom onset. RNA (nasopharyngeal/throat swabs) undetectable within 6-22 days (mean: 12 days) after illness onset. RNA (faecal samples) positive 3-13 days after illness onset in five patients, and within 18-30 days after illness onset. All patients discharged when they recovered with two consecutive RNA (respiratory samples) tested negative.	**Confirmed transmission** Transmission from infected child to adult contacts: N=2 3-month-old infant whose 2 parents developed symptomatic COVID-19 7 days after looking after the infant. Source of infant infection not reported. Infant had positive nasopharyngeal swabs for 8 days. Number of secondary symptomatic cases including the child and his/her family members who were exposed to a common index case and developed symptoms: 1 to 4 (mean: 2.43). **Mean time to transmission/symptoms onset** Not reported. Parents developed symptomatic COVID-19 7 days after looking after the infant.
Canarutto[4] **Italy** **Case report** **DOI:** https://doi.org/10.1002/ppul.24754	**Population setting:** 1 patient admitted to a Children's Hospital **Demographics:** *Age:* 32 days *Gender:* Male **Clinical characteristics:** *Presentation:* low grade fever, rhinitis and cough (1 day history). RNA positive nasopharyngeal swabs.	**Confirmed transmission** Transmission from infected child to adult contacts: N=0 No transmission of the virus to medical staff was documented. Transmission status to family members not reported. **Mean time to transmission/symptoms onset** Not applicable
Danis[3] **France**	**Population setting:** 1 adult index case (laboratory-confirmed), 11 secondary cases and 1 tertiary case. 1 paediatric secondary case (laboratory-confirmed) and 112 school contacts.	**Confirmed transmission** Transmission from infected child: N=0

Case Series (cluster) **DOI:** 10.1093/cid/ciaa424	In total, 172 contacts (112 school-based) and 73 had RT-PCR tests. **Demographics (paediatric case):** *Age:* 9 years *Gender:* Male **Clinical characteristics (paediatric case):** *Presentation:* symptomatic (unspecified)	**Mean time to transmission/symptoms onset** Not applicable **Other relevant findings** Possible transmission of other viruses (picornavirus) by paediatric case: 3/10 (30%) of contacts.
Jung[12] **South Korea** **Case report** **DOI: https://doi.org/10.1016/j.cmi.2020.06.021.**	**Population setting:** 1 patient admitted to hospital with a 1-day history of headache. SARS-CoV-2 PCR negative on admission. 81 close contacts and 1,125 casual contacts (219 inpatients with guardians, 81 discharged patients with guardians, 48 visitors and 858 health-care workers). **Demographics:** *Age:* 9 years *Gender:* Female **Clinical characteristics:** Headache and fever.	**Transmission** Possible transmission from child to adult contact: N=1. 1/1,152 contacts tested positive: mother of a hospitalised infant (22 days after birth) who shared the 6-patient room directly across from the index patient (approximately 3m distance). This mother had spent 2 hours in the 6-patient room on 28 March and 20 hours from 30 to 31 March (date index patient received positive test result).
Laxminarayan[15] **India** **Epidemiological study (surveillance data)** DOI: (preprint) **https://doi.org/10.1101/2020.07.14.20153643**	**Population setting:** 4,206 confirmed cases and 64,031 contacts from public health surveillance data in Tamil Nadu and Andhra Pradesh states. 288 child index cases with 2,107 contacts (473 children, 1,634 adults). **Demographics (index cases):** *Age group* 0-4 years: 36 5-17 years: 252 ≥ 18: 3,918 *Gender:* Male n = 2,833 (67.4%), female n = 1,371 (32.6%), unknown n=2 (<1%), **Clinical characteristics:** Not reported	**Transmission** *From 288 child index cases* SARS-CoV-2 positive child contacts: 31/473 (7%) SARS-CoV-2 positive adult contacts: 205/1,634 (12.5%) **Mean time to transmission/symptoms onset** Not reported
Le[5]	**Population setting:** 1 patient admitted to a Children's Hospital	**Confirmed transmission**

Vietnam **Case report** **DOI:** https://doi.org/10.1016/S2352-4642(20)30091-2	**Demographics:** *Age:* 3 months *Gender:* Female **Clinical characteristics:** *Presentation:* rhinorrhoea, nasal congestion, fever. RNA positive nasopharyngeal swabs.	Transmission from infected child to adult contacts: N=0 At hospitalisation (day 6 after symptom onset) the infant was isolated with her mother. The infant's mother was advised to wear a surgical face mask, practiced hand hygiene, and continued to breastfeed the infant. Maternal repeated nasopharyngeal swabs were negative for SARS-CoV-2. **Mean time to transmission/symptoms onset** Not applicable
Lin[6] **China (Chongqing)** **Case Report** **DOI:** https://doi.org/10.1002/ppul.24763	**Population setting:** 1 patient admitted to a quarantine ward in a local country hospital **Demographics:** *Age:* 7 years *Gender:* Female **Clinical characteristics:** *Presentation:* Complaint of nasal obstruction for 2 days without cough, fever, dyspnoea or diarrhoea. RNA positive throat swabs.	**Confirmed transmission** Possible transmission from infected child to adult contacts: N=1 On 21 Jan 2020 the girl's father drove and then took a bus to Xiangyang, Hubei province where he stayed overnight but did not have close contact with anybody except family members. On 22 Jan 2020, the father self - drove from Xiangyang, Hubei to Chongqing city with the girl, her grandparents, mother, and 2 - year - old brother, arriving in the early morning of 23 Jan. **Mean time to transmission/symptoms onset** Girl's father presented with symptoms 5 days after meeting his daughter.
Lucar[13] **Case report** **USA** **DOI:**	**Population setting:** 1 index case airlifted to hospital following car accident and placed under general anaesthesia for orthopaedic surgical intervention 1. SARS-Cov-2 test positive on hospital day 2. 11 healthcare practitioners (HCP) present in the operating room. **Demographics:** *Index case*	**Transmission:** Confirmed transmission from child to HCP contacts: N=0. 1/11 (assisted with intubation) dry cough a few hours post-procedure; SARS-CoV-2 test negative.

https://doi.org/10.1016/j.ajic.2020.05.036	*Age:* 17 years *Gender:* male *Health care practitioners:* Not reported **Clinical characteristics:** *Index case:* Post-operative cough which resolved within 24 hours, no other symptoms up to 14 days after the day of the accident. RNA positive nasopharyngeal swabs.	10/11 no symptoms throughout the 14-day monitoring period and were not offered SARS-CoV-2 testing. HCP wore COVID-19 personal protective equipment (PPE) consisting of N95 mask, face shield, gowns, and gloves.
Mannheim[16] **USA** **Case series** **DOI:** https://doi.org/10.1093/jpids/piaa070	**Population setting:** 64 paediatric (≤ 17 years) laboratory-confirmed SARS-CoV-2 cases reported to the Chicago Department of Public Health**.** 15 households with transmission data. **Demographics (n=64):** *Median age:* 11 (IQR 7-16) *Gender:* Male n = 36 (56%), female n = 28 (44%) **Clinical characteristics (n=64):** *Presentation:* Cough n=48 (75%); nasal congestion/rhinorrhea/anosmia n=19 (30%); sore throat n= 16 (25%); dyspnoea n=17 (27%); fever n=36 (56%); headache n=18 (28%); myalgia n=15 (23%); chills n=5 (8%); diarrhoea n=10 (16%); abdominal pain n=8 (13%); nausea/vomiting n=4 (6%); *Severity of infection:* Hospitalised n=10 (16%); hospitalised in ICU n=7/10 (70%)	**Confirmed transmission (15 households)** Households with child index case: 4/15 (26%) Child to child: 2/15 Child to adult: 2/15 Number of secondary cases: not reported **Mean time to transmission/symptoms onset** Not reported
Nassih[14] **Morocco** **Case report** **DOI: 10.1007/s12098-020-03382-0**	**Population setting:** 1 laboratory-confirmed SARS-CoV-2 case **Demographics:** *Age:* 2 years *Gender:* Female **Clinical characteristics:** Asymptomatic. RNA positive nasal swabs.	**Confirmed transmission** Transmission from infected child: n=0 Child cared for by mother for duration of illness (1 month) using airborne and contact precautions and mother remained PCR and serology negative. **Mean time to transmission/symptoms onset** Not applicable

Posfay-Barbe[8] **Switzerland** **Case series** **DOI:** https://doi.org/10.1542/peds.2020-1576	**Population setting:** 39 patients <16 years old with SARS-CoV-2 infection (7 inpatients, 32 outpatients) and 111 household contacts **Demographics:** *Median age (IQR):* 11.1 years (5.7 – 14.5) *Gender:* Male n = 17 (44%), female n = 22 (56%) **Clinical characteristics:** *Presentation:* cough 32 (82%); fever 26 (67%); nasal discharge 25 (64%); headache 22 (56%); sore throat 14 (36%); shortness of breath 13 (33%); myalgia 13 (13%); abdominal pain 11 (28%); anosmia 8 (21%); arthralgia 7 (18%); diarrhoea 7 (18%); fatigue 5 (13%); rash 5 (13%); dysgeusia 4 (10%); nausea 4 (10%); vomiting 3 (8%); thoracic pain 2 (5%); conjunctivitis 1 (3%)	**Confirmed transmission** Possible transmission: Cluster with a child developing symptoms prior to any other household contacts: N=3/39 (8%) Number of secondary cases: 4 (3 mothers and 1 father) **Mean time to transmission/symptoms onset** Not reported
Qiu[7] **China** **Case report** **DOI:** 10.1097/INF.0000000000002720	**Population setting:** 1 patient admitted to a Children's Hospital **Demographics:** *Age:* 8 months *Gender:* Male **Clinical characteristics:** *Presentation:* poor growth, malnutrition, cough RNA positive nasopharyngeal and rectal swabs.	**Confirmed transmission** Transmission from infected child to adult contacts: N=0 **Mean time to transmission/symptoms onset** Not applicable
Somekh[17] **Israel** **Case series** **DOI:** 10.1097/inf.0000000000002783	**Population setting:** 13 family clusters (36 adults, 58 children) Index case: first case of the infection in the family **Demographics:** *Age:* Children: 6 months to 17 years Adults: 18 to 48 years *Gender:* Not reported **Clinical characteristics:** Not reported	**Confirmed transmission** Cluster with child index case: 1/13 (8%) (14.5-year-old male). Transmission from infected child to adult contacts: not reported Transmission from infected child to child contacts: not reported Number of secondary cases: not reported **Mean time to transmission/symptoms onset** Not reported
Szablewski[11] **USA**	**Population setting:** 1 teenage COVID-19 case at an overnight camp in Georgia. Surveillance System data on 597 Georgia residents who were at the camp: 346 campers; 134 trainees; 117 staff	**Confirmed transmission** Transmission from infected child: unclear

Case series (surveillance data) **DOI: 10.15585/mmwr.mm6931e1**	*Linked cases:* a positive viral RNA test arrival to 14 days after departure **Demographics:** *Index case:* Not reported *Median camper age:* 12 years (range = 6–19) *Median staff member and trainee age:* 17 years (range 14-59) *Age group* 6-10 years n=100 11-17 years n=409 18-21 years n=81 22-59 years n=7 *Gender* Index case: Not reported Campers: female 182/346 (53%) Staff and trainees: female 148/251 (59%) **Clinical characteristics:** *Index case:* chills *Cases (n= 136 with available data):* no symptoms n=36 (26%); subjective or documented fever n=60 (44%); headache n=61 (45%); sore throat n=46 (34%).	COVID-19 positive: 260/344 (76%) Overall attack rate: 260/597 (44%) Attack rate 6–10 years: 51% Attack rate 11–17 years: 44% Attack rate 18–21 years: 33%
van der Hoek[18] **The Netherlands** **Prospective observational study (surveillance data)** **DOI: https://www.ntvg.nl/artikelen/de-rol-van-kinderen-de-transmissie-van-sars-cov-2/abstract** **Note: translated using google scholar**	**Population setting**: 732 transmission pairs from Dutch National Institute for Public Health and the Environment national surveillance data **Demographics:** Aged 4-12 years n=9 Aged ≥ 20 years n=31 **Clinical characteristics:** Not reported	**Confirmed transmission** Transmission from infected child to child: N=2 *Note:* the source in one of these cases was aged between 15 and 20 years. **Mean time to transmission/symptoms onset** Not applicable
Wongsawat[10]	**Population setting:** 3 paediatric COVID-19 cases and 3 adult care givers	**Confirmed transmission**

Thailand **Case series** **DOI: doi.org/10.1111/jpc.14965**	**Demographics:** *Age range:* 4 to 8 years *Gender:* Male n=2, female n = 1 **Clinical characteristics:** All children had very mild respiratory symptoms for 1 day before admission. RNA positive nasopharyngeal and throat swabs.	Transmission from infected child to adult contacts: N=0 1 case was isolated with his grandfather who was also infected with COVID-19, and 2 cases were isolated with healthy caregivers. During isolation, children and caregivers were advised to wash hands frequently, not share personal items and were provided surgical masks. **Mean time to transmission/symptoms onset** Not applicable
Wu[2] **China** **Case series** **DOI: 10.1542/peds.2020-0961**	**Population setting:** 74 paediatric laboratory-confirmed SARS-CoV-2 cases admitted in Qingdao Women's and Children's Hospital and Wuhan Children's Hospital **Demographics:** *Age:* ≤ 3 months: 7 (9.5%) 3 to 6 months: 4 (5.4%) 6 months to 1 year: 5 (6.76%) 1 to 3 years: 12 (16.2%) 3 to 10 years: 31 (41.9%) >10 years: 15 (20.3%) *Gender:* Male n = 44 (59.5%), female n = 30 (40.5%) **Clinical characteristics:** *Presentation:* Cough n=24 (32.4%); fever n=20 (27%); fatigue n=5 (6.8%); chest congestion n=4 (5.4%); anorexia n=3 (4%); diarrhoea (n=3 (4%); dyspnoea n=2 (2.7%); headache n=2 (2.7%), expectoration, n= 2 (2.7%) *Severity of infection:* severe pneumonia n=1; mild pneumonia n= 29; acute upper respiratory tract infection n= 24; asymptomatic infection n= 20 RNA positive after symptom onset: Median 2 days (range, 1-6)	**Confirmed transmission** Transmission from infected child to contacts: N=0 **Mean time to transmission/symptoms onset** Not applicable

	RNA (faecal samples) positive: 10/74 (13.51%) Viral RNA remained positive in stools of 8 convalescent patients after respiratory specimens were negative, for a median of 11 days (range 5 to 23)	
Xu[9] **China** **Epidemiological study** **DOI (preprint):** 10.1101/2020.03.02.20029868	**Population:** 419 index patients and their 595 household secondary infections. Index patient: first case patient and the only person who returned home from Wuhan/other cities in Hubei Province in the household. Secondary cases: patients who had no known exposure to virus sources outside of the family. **Setting:** Local Heath Commissions' public disclosures **Demographics**: Not reported **Clinical characteristics:** Not reported	**Confirmed transmission** No case infected by index patient (first case patient) 15 years of age or younger was reported. 3 index patients were aged <18 years and infected 3 secondary cases, one aged 0-17 years, one 18-49 years and one 65+ **Mean time to transmission/symptoms onset** No data on child transmission specified. In the full data set, the time between the onset of symptoms in a case patient and the onset of symptoms in the household contacts infected by that patient, was 5.9 days.
Zhu[19] **Five countries (China, Singapore, South Korea, Japan, and Iran)** **Secondary data analysis of published data** **DOI (preprint):** 10.1101/2020.03.26.20044826	**Population:** 31 household transmission clusters, 94 cases, including 20 paediatric SARS-CoV-2 cases **Setting:** review of published literature and datasets between December 2019 and March 2020 **Demographics of included children household transmission clusters (n=20):** *Age (range):* 3 months to 10 years *Gender:* Male n = 13, female n = 7 **Demographics of children from all identified datasets**: *Mean age (n = 103):* 5.35 (± 4.65) *Gender (n = 105):* 56.19% female **Clinical characteristics from identified datasets:** *Presentation (n=81):* Fever 77%; cough 59%; rhinorrhoea 17%; tachypnoea 12%; nausea/vomiting 12%; sore throat 12%; chills 11%; retraction 11%; diarrhoea 6%; fatigue/myalgia/weakness 2%	**Confirmed transmission** Cluster with paediatric index case: 3/31 (9.7%)* Number of secondary cases: 5 Cluster with paediatric index case, assuming that asymptomatic children are being mistakenly overlooked as the index case in familial clusters: 6/28 (21%) **Mean time to transmission/symptoms onset** Not reported * Note: One case included here is also included in the case series by Cai et al.[1]

	Severity of infection (n = 102): Asymptomatic 19%; Mild - Moderate 69%; Severe 12%	
School-based transmission		
Dub[20] **Finland (Helsinki)** **Retrospective cohort study** DOI: (preprint) **https://doi.org/10.1101/2020.07.20.20156018**	**Population setting**: 2 COVID-19 cases (1 paediatric and 1 staff) in 2 schools and 184 contacts, with nested household transmission study *Paediatric case:* 1 child and 121 close contacts: 103 school contacts (96 pupils from 4 classes and 8 school staff) and 18 sports training contacts (16 children and 2 adults). *Adult case:* 1 staff member and 63 exposed persons: 52 pupils (2 classes) and 11 staff members. *Household transmission study (contacts of secondary cases identified from adult case)*: N=33 (close household contacts n=20, regular household contacts n=9, extended household contacts n=4). **Demographics (paediatric case):** *Age:* 12 years *Gender:* not reported **Clinical characteristics (paediatric case):** Minor symptoms *Household transmission study (n=8)* Fever n=3 (38%); no symptoms n= 3 (38%); cough n=2 (25%); diarrhoea n=2 (25%); respiratory n=1 (13%); sore throat n=1 (13%); headache n=1 (13%); runny nose n=1 (13%)	**Transmission** Transmission from child (89/121 contacts tested, nasopharyngeal and serum specimens): N=0 Transmission from staff (42/52 contacts tested, serum specimens): Staff to child: N=7 Staff to staff: N=1 *Household transmission study (7 cases and 29 contacts, serum specimens)* Possible transmission from child to contact: N=2 Number of secondary cases: 5
Heavy[21] **Ireland** **Epidemiological study** **DOI:** https://doi.org/10.2807/1560-7917.ES.2020.25.21.2000903	**Population setting:** 6 COVID-19 cases (3 paediatric and 3 adult) with a history of school attendance and 1,155 contacts (1,025 school contacts, 130 other settings) *Paediatric cases:* 1 primary school, 2 secondary school (905 school contacts, 84 other) *Adult cases:* 1 teacher, 2 adults providing educational sessions in schools for up to 2 hours (120 school contacts, 46 other) **Demographics (paediatric cases):** *Age:* 10-15 years: 3	**Confirmed transmission** Transmission from infected child: N=0 **Mean time to transmission/symptoms onset** Not applicable.

	Gender: Not reported **Clinical characteristics (paediatric cases):** *Presentation:* Fever 2, asymptomatic 1	
Macartney[22] **Australia (New South Wales)** **Prospective cohort study** **DOI:** **https://doi.org/10.1016/S2352-4642(20)30251-0**	**Population setting:** 27 COVID-19 cases (12 children, 15 staff) and 1,448 (1,185 student contacts, 263 staff contacts) close contacts from 15 schools (10 high schools, 5 primary schools) and 10 early childhood education and care (ECEC) settings. 633/1,448 (43.7%) had nucleic acid testing, or antibody testing. *Index case*: first identified laboratory-confirmed case who attended the facility while infectious. *Primary case*: initial infectious case or cases in that setting, and might or might not have been the index case. *Secondary case:* close contact with SARS-CoV-2 infection (detected through nucleic acid testing or serological testing, or both), which was considered likely to have occurred via transmission in that educational setting. *High schools* 12 primary cases (8 students, 4 staff) with 696 close contacts (600 students, 96 staff). *Primary schools* 5 primary cases (1 student, 4 staff) with 218 close contacts (179 students, 39 staff). *ECEC* 10 primary cases (3 children, 7 staff) with 534 close contacts (406 children, 128 staff). **Demographics:** *Age* High schools (n=8): Median 15 (range 14–16) Primary schools (n=1): 10 ECEC (n=3): median 2 (range 2–3) *Gender* High schools (n=8): Male 5, female 3 Primary schools (n=1): 1 female ECEC (n=3): Male 1, female 2 **Clinical characteristics:**	**Positive cases** 18 secondary cases: 10 children, 8 staff in 4/25 settings Schools (n=5 cases): 2 secondary schools with 2 child and 1 staff case 1 primary school with 1 child case and one staff case 1 ECEC setting (n=13 cases): 7 children, 6 staff **Confirmed transmission** All settings, child case to child contacts: 2/649 (0.3%) All settings, child case to staff contacts: 1/103 (1%) All settings, staff contacts to child case: 8/536 (1.5%) All settings, staff contacts to staff case: 7/160 (4.4%) **Mean time to transmission/symptoms onset** The median time that primary cases attended the setting while infectious was 2 days (range 1–10).

	Not reported	
Stein-Zamir[23] **Israel** **Case series** **DOI: 10.2807/1560-7917.ES.2020.25.29.2001352**	**Population setting:** 2 student COVID-19 cases in 1 high school (not epidemiologically linked) and 1,312 contacts (1,161 student, 151 staff) **Demographics:** *Age:* Not reported *Gender:* Not reported **Clinical characteristics:** *Presentation:* mild - anosmia, ageusia, fever and headache	**Confirmed transmission** Possible transmission: Positive cases (n=178) Students: 153/1,161 (13.2%) Staff: 25/151 (16.6%) COVID-19 rates were higher in junior grades (7–9) than in high grades (10–12). Additionally 87 confirmed cases among close contacts (siblings, recreational contacts and parents of students; family members of school staff) of the school's cases. **Mean time to transmission/symptoms onset** Not applicable.
Yoon[24] **South Korea** **Secondary analysis of press release data** **DOI: https://doi.org/10.1101/2020.08.03.20165589**	**Population setting:** Publically available data (press release) on 45 paediatric cases in 40 schools and kindergartens (12 high schools, 8 middle schools, 15 elementary schools, 5 kindergartens), and at least 10,903 contacts **Demographics:** *Age group* 4-5 years: 5 6-12 years: 19 13-15 years: 8 16-18 years: 13 *Gender:* Not reported **Clinical characteristics:** Not reported	**Confirmed transmission** Transmission from infected child: N=1 Number of secondary cases: 2 An 11-year-old child (in elementary school) transmitted the virus to two other children. One child was infected in the same classroom; the other was not in the same class, but was infected at the same exercising gym out of school. **Mean time to transmission/symptoms onset** Not applicable.
Yung[29] **Singapore**	**Population setting:** 3 SARS-CoV-2 cases (2 paediatric and 1 adult) who attended 2 preschools and 1 secondary school and 119 contacts (42 from paediatric cases, 93 from adult case)	**Confirmed transmission** Transmission from infected child: N=0

Epidemiological study **DOI:** **https://doi.org/10.1093/cid/ciaa794**	Close contacts (e.g., students from the same class) were placed under quarantine. Non-close contacts were not quarantined and continued with classes **Demographics (paediatric cases):** *Age:* 12 years, 5 years *Gender:* Not reported **Clinical characteristics:** Not reported, SARS-CoV-2 positive from contact tracing following their exposures to adult family household members who were part of a community cluster.	**Mean time to transmission/symptoms onset** Not applicable.
Transmission modelling		
Dattner[27] **Israel** **Modelling study** DOI: **(preprint)** **https://doi.org/10.1101/2020.06.03.20121145**	**Population setting:** 637 households comprising 3,353 people in Bnei Brak. Household size ranged from 2 to >10. (Household inclusion criteria: at least 2 members, with all household members tested and at least 1 with PCR confirmed COVID-19). **Demographics:** *Age group* 0-19 years: 1,544 20+ years: 1,809 **Clinical characteristics:** PCR confirmed COVID-19 Total: 1,510/3,353 (45%) 0-19 years: 512/1,544 (33%) 20+ years: 998/1,809 (55%) **Model parameters data sources** Discrete stochastic dynamic model with based on surveillance data, parameter estimates obtained by a maximum likelihood method, where the likelihood function is computed based on the stochastic model via simulations.	**Transmission modelling** Children, when infected, are somewhat less prone to infect others compared with adults, although the result is not statistically significant. The infectivity of children is estimated to be HR 85% [95% CI 65%, 110%] relative to that of adults.
James[28] **New Zealand**	**Population setting:** Confirmed and probable COVID-19 cases, n=1,499 (domestic cases n=924 (62%); imported cases n=575 (38%)) from a completed outbreak	**Transmission:** Children infected fewer people on average and had a lower secondary attack rate compared with adults and the elderly.

Modelling study DOI: **(preprint) https://doi.org/10.1101/2020.07.21.20159335**	**Demographics:** *Age group* under 10 years: 35 0-65 years: 1,261 over 65 years: 172 Gender: Not reported **Clinical characteristics:** Not reported **Model parameters data sources** Comprehensive dataset from a completed outbreak. Reconstructed multiple instances of the transmission tree using a Monte-Carlo technique for cases missing potential index case or where there were multiple potential index cases	*Expected number of secondary infections caused by age group at no alert level (pre 25 March)* Under 10 years: 0.87 0-65 years: 1.49 over 65 years: 1.51 *Expected number of secondary infections caused by age group at alert level 4 (post 25 March)* Under 10 years: < 1 0-65 years: < 1 over 65 years: > 1
Zhao[26] **China (Wuhan City)** **Mathematical model** **DOI (preprint):** 10.1101/2020.03.05.20031849	**Population data:** 29 COVID-19 cases, 10 with history of exposure to Huanan seafood market, 19 without exposure **Model parameters data sources** • Age group proportions, birth rate and death rate - Wuhan Statistical Yearbook Other parameters – literature	**Model with four-age-groups:** Highest transmissibility occurred between the age groups 15 – 44 years and 45 – 64 years, among those ≥ 65 years, or from 45 – 64 years to ≥ 65 years. Lowest transmissibility occurred from age group 0-14 years to 15 – 44 years, or from 45 – 64 years to ≤14 years. **Model with five-age-groups:** Highest transmissibility occurred between age group 25 – 59 years and ≥ 60 years, or among 25 – 59 years. Lowest transmissibility occurred from age group 15 – 24 years to 25 – 59 years, or from age group 0-5 years to 6-14 years, or, to 15-24 years.

Table 2 Studies in childcare and school settings without transmission chain

Author Country Study design	Population setting Patient demographics Clinical characteristics	Primary outcome results
Armann **Germany (Saxony)** **Epidemiological study (SchoolCoviDD19 study)** **DOI: (preprint) http://dx.doi.org/10.2139/ssrn.3651210**	**Population Setting:** 1,538 students and 507 staff from 13 schools in Saxony, after the reopening of schools on 18 May. The number of participants ranged from 21 to 573 per individual school. **Demographics:** *Students* *Age:* median: 15 years (IQR: 14-16 years) *Gender:* 802 female (52%) *Teachers* *Age:* median: 51 years (IQR: 37-57 years) *Gender:* 357 female (70%) **Clinical characteristics:** *Students* Previously tested positive for SARS-CoV-2 by PCR: n=5 (0.3%) *Teachers* Previously tested positive for SARS-CoV-2 by PCR: n=0 (0%) **Other characteristics:** *Students* Household contact of participant previously tested positive for SARS-CoV-2 by PCR: n=22 (1.4%) Regular social contacts outside the student's household/classroom: n=1230 (80%) *Teachers* Household contact of participant previously tested positive for SARS-CoV-2 by PCR: n=2 (0.4%)	**Seropositivity (IgG antibodies)** Total population: 12/2045 (0.6%) Students: 11/1538 (0.7%) Teachers: 1/507 (0.2%) The largest number of seropositive participants in any one school was four. The seroprevalence ranged from 0 to 2.2 per school. Of all participants with a personal history of a SARS-CoV-2 infection (all students), 4/5 were seropositive. Of all participants with a household history of a SARS-CoV-2 infection, 23/24 were seronegative. **Conclusion** A single cluster of infections in the participating schools could not be detected, even though at least three schools did have confirmed SARS-CoV-2 cases before the lockdown in Saxony. The prevalence of IgG antibodies in older students and their teachers against SARS-CoV-2 remains extremely low after the first wave of the corona pandemic in Germany.
Brown[61] **USA**	**Population Setting:** 1 SARS-CoV-2 positive teacher plus 21 students with known exposure through classroom contact (5 interactive classroom	**Seropositivity (IgG antibodies)** Interactive classroom contact: 2/5 (40%) Noninteractive classroom contact: 0/12 (0%)

Epidemiological study **DOI: 10.3201/eid2609.201802**	contact, mean in-class time 108 minutes; 16 noninteractive classroom contact only, mean in-class time 50 minutes) **Demographics:** *Students* Median age: 17 years (range 5–18) Gender: not reported	
Desmet[62] **Belgium** **Cross sectional study** **DOI: (preprint)** 10.1101/2020.05.13.20095190	**Population Setting:** 84 children from 8 different daycare centres (1 in Brussels, 3 in Wallonia and 4 in Flanders) in Belgium shortly after the start of the epidemic. Part of a larger nasopharyngeal carriage study that started in Belgium in 2016 to monitor changes in the proportions of pneumococcal serotypes in children between 6 and 30 months of age. **Demographics:** *Age:* 6-30 months *Gender:* 43 (52.4%) female **Clinical characteristics** Common cold symptoms: 51.2%	**Transmission patterns** Shortly after the start of the epidemic (29 Feb) and before the lockdown in Belgium (18 Mar) no (asymptomatic) carriage of SARS-CoV-2 was detected in a random sample of children attending daycare via real-time PCR. No information on COVID-19-like symptoms in household members or caregivers. **Conclusion** Results do not suggest a role of daycare attendance in early transmission.
Fontanet A[59] **France (Oise)** **Retrospective closed cohort study** **DOI: (preprint)** 10.1101/2020.04.18.20071134	**Population Setting:** 661 pupils, parents, siblings and staff of a high school linked to a cluster of COVID-19 in Oise, approximately 8 weeks after the most likely introduction of SARS-CoV-2 in this community. *School-based participants (n=326):* Pupils*:* 240 (36.3%); Teachers: 53 (8%); school staff: 27 (4.1%) *Parents and siblings (n=345):* parents 211 (31.9%); siblings 127 (19.2%). *Others:* 3 (0.5%) *Recruitment rate:* 326/878 (37%) **Demographics:** *Age:* median age: 37 years (IQR: 16-47); 2 participants > 65 years. *Gender: 251 male (38%)* **Clinical characteristics: all participants (n= 661)** Respiratory symptoms up to 1 week before blood sampling: 452 (68.4%) Major symptoms (fever, dry cough, dyspnoea, anosmia and ageusia): 321 (48.6%)	**Infection attack rate (IAR) (proportion of all participants with confirmed SARS-CoV-2 infection):** 171/661, 25.9% (95% CI 22.6-29.4). IAR was higher in the high school group (pupils, teachers, and school staff) than in parents and siblings (P <0.001). *IAR by group* Pupil (n=240): 92 (38.3%) Teacher (n=53): 23 (43.4%) School staff (n=27): 16 (59.3%) Parent of a pupil (n=211): 24 (11.4%) Sibling of a pupil (n=127): 13 (10.2%) Other (n=3): 3 (100.0%) *By age group* ≤14 (n=37): 1 (2.7%)

	Minor symptoms (sore throat, rhinitis, muscle pain, diarrhoea, headache, asthenia): 131 (19.8%) No symptoms: 209 (31.6%) Most common symptoms: Rhinitis (38.3%), cough (35.4%), headache (30.9%), asthenia (29.6%), sore throat (26.8%), and fever (26.2%). Hospitalisation rate: 5.3% (95% CI 2.4 –9.8) **Participants with confirmed SARS-CoV-2 infection (n=171)** Major symptoms: 70.8% (95% CI 63.3-77.5) Minor Symptoms: 12.3% (95% CI 7.8-18.2) No symptoms: 17.0% (95% CI 11.2 – 23.4)	15-17 (n=205): 82 (40.0%) 18-44 (n=177): 39 (22.0%) 45-64 (n=239): 49 (20.5%) ≥65 (n=2) 0 (0.0%) **Transmission patterns:** Number of new cases decreased after beginning of the school holidays and again after local confinement measures were introduced in Oise.
Fontanet B[58] **France** **Retrospective closed cohort study** **DOI (preprint): doi.org/10.1101/2020.06.25.20140178**	**Population Setting:** 1,340 pupils, parents, siblings and staff across 6 primary schools (follow-up seroepidemiologic investigation from the same city, as described Fontanet et al.[59]) *School-based participants (n=580):* Pupils*:* 510; Teachers: 42; school staff: 28 *Parents and relatives (n=760):* parents 641; relatives 119 **Demographics:** *Age group* ≤7 years: 161 (12%) 8-9 years: 205 (15.3%) 10-11 years: 173 (12.9) 12-17 years: 78 (5.8%) 18-44 years: 542 (40.5%) 45-64 years: 179 (13.4%) ≥65 years: 2 (0.1%) *Gender:* 571 male (42.6%)	**Infection attack rate (IAR) (proportion of all participants with confirmed SARS-CoV-2 infection):** 139/1340 (10.4%). IAR was higher in the high school group (pupils, teachers, and school staff) than in parents and siblings (P <0.001). *IAR by group* Pupil (n=510): 45 (8.8%) Teacher (n=42): 3 (7.1%) School staff (n=28): 1 (3.6%) All relatives living in the same household (n=119): 14 (11.8%) *By age group* ≤7 years: 10 (6.2%) 8-9 years: 20 (9.8%) 10-11 years: 16 (9.2) 12-17 years: 12 (15.4%) 18-44 years: 62 (11.4%) 45-64 years: 19 (10.6%) ≥65 years: 0 (0%)
Torres[60] **Chile**	**Population Setting:** 1 private school, 1,009 students (38% of the entire student body) and 235 staff (74% of the entire school staff) Index case: staff member who worked with the entire preschool and	**Prevalence of anti-SARS-CoV-2 antibodies 8-10 weeks after a school outbreak**

Cross sectional study **DOI:** **https://doi.org/10.1093/cid/ciaa955**	elementary school staff, and was present at all of the parent-teacher meetings **Demographics:** Students *Mean age (SD):* 10.8 years (4.1) *Gender:* 46% female Staff *Mean age (SD):* 42.8 years (10.4) *Gender:* 73% female **Participants with confirmed SARS-CoV-2 infection via PCR at time of outbreak: (n=25)** Students: 7 (28%) Staff: 18 (72%)	Students (n=1,009): 9.9% (95% CI: 8.6-11.5) Staff (n=235): 16.6% (95% CI: 12.1- 21.9)

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