COVID-19 transmission in educational institutions August to December 2020, Rhineland-Palatinate, Germany: a study of index cases and close contact cohorts

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Short title: COVID-19 in educational institutions

NOTE: This preprint reports new research that has not been certified by peer review and should not be used to guide clinical practice.
Abstract

Background
The lack of precise estimates on transmission risk hampers rational decisions on closure of educational institutions during the COVID-19 pandemic.

Methods
Secondary attack rates (SARs) for schools and day-care centres were calculated using data from state-wide mandatory notification of SARS-CoV-2 index cases in educational institutions and additional information on routine contact tracing and PCR-testing.

Findings
From August to December 2020, every sixth of overall 784 independent index cases caused a transmission in educational institutions (risk 0·17, 95% CI 0·14–0·19). In a subgroup, monitoring of 14,594 institutional high-risk contacts (89% PCR-tested) of 441 index cases revealed 196 secondary cases (SAR 1·34%, 1·16–1·54). Transmission was more likely from teachers than from students/children (incidence risk ratio [IRR] 3·17, 1·79–5·59), and from index cases in day-care centres (IRR 3·23, 1·76–5·91) than from those in secondary schools. In 748 index cases, teachers caused four times more secondary cases than children (1·08 vs. 0·25 secondary cases per index, IRR 4·39, 2·67–7·21). This difference was mainly due to common transmission from teacher index cases to teacher contacts (mean secondary cases 0·56 teacher to teacher vs. 0·04 child to teacher, IRR 13·3, 6·6–26·7).

Interpretation
In educational institutions, the risk of contacts to a confirmed COVID-19 case for infection is one percent, but varies depending on type of institution and index case. Hygiene measures targeting the day-care setting and teacher-to-teacher transmission are priorities in reducing the burden of infection and may promote on-site education during the pandemic.

Funding
No particular funding was received for this study.
Research in context

Evidence before this study

We searched PubMed on Jan 27, 2021, without any language restrictions for all articles in which the title or abstract contained the search terms “COVID 19” or “corona”, and “school”, “education*”, or “daycare”, and “transmission”, and “risk”, “attack rate”, or “SAR”, and screened 175 results for original research or reviews on COVID-19 transmission risk in the educational setting. Following a similar strategy, we also searched Google Scholar, SSRN, medRxiv, and the reference lists of identified literature. We found one recent systematic review that pooled findings from five small-scale cohort studies on COVID-19 transmission risk published until 14th September 2020 on overall 18 index cases and 3,345 contact persons into a combined infection attack rate estimate of 0.08% (95% CI 0.00-0.86). Since then, another three cohort studies on transmission risk in schools and day-care centres have been published from Germany and Italy including 135 index cases and 4,188 contact persons and reporting secondary attack rates between one and three percent.

The aforementioned systematic review found that, stratified by role of the index case, there was a non-significant trend towards higher infection attack rates in staff (0.70%, 0.00-3.56) than in student index cases (0.15%, 0.00-0.93), but recommended further research to confirm this trend. Similarly, a cross-sectional study using data from 30 outbreaks during the first COVID-19 wave in 2020 in the U.K. pointed towards an increased risk of SARS-CoV-2 in staff compared to students.

A number of modelling studies from the first wave of COVID-19 provide inconclusive results. While two publications, one from several countries and one from Switzerland, concluded that school closures contributed markedly to the reduction of transmission and mobility, two other studies, one using cross-country data and one from Japan rated school closures among the least effective measures to reduce COVID-19 incidence rates.

Added value of this study

By both, the number of index cases and contact persons studied, this cohort study is more than twice larger than the total of all published cohort studies on COVID-19 transmission risk in schools and day-care centres combined. Besides, this is the first study on transmission risk in schools to incorporate a period of drastically changing background incidence in the source
population. Based on data that emerged from the current public health practice in Germany, which frequently incorporates routine PCR-testing during active follow-up of asymptomatic high-risk contacts to index cases, this study provides a precise estimate of the true underlying SARS-CoV-2 transmission risk in schools and day-care centres. Thanks to the large sample size, this study allows for a meaningful examination of differences in the risk of transmission with respect to the characteristics of the index case. We found that the individual risk of acquiring SARS-CoV-2 among high-risk contacts in the educational setting is 1.3%, but that this risk rises to 3.2% when the index case is a teacher and to 2.5% when the index case occurs in a day-care centre. Furthermore, we could show that, on average, teacher index case produced about four times as many secondary cases as student/child index cases. Despite the relatively small proportion of teachers among index cases (20%), our study of transmission pathways revealed that the majority of all secondary cases (54%), and the overwhelming majority of secondary cases in teachers (78%) were caused by teacher index cases.

Implications of all the available evidence

In this setting, where preventative measures are in place and COVID-19 incidence rates were rising sharply in the population, we found a low and stable transmission risk in educational institutions, which provides evidence for the effectiveness of current preventative measures to control the spread of COVID-19 in schools. The identification of a substantial transmission risk within the group of teachers, but not between children/students and teachers indicates the need for an additional focus on infection prevention during teachers’ activities outside the classroom, e.g. in staff-meetings and in break rooms. Our findings on substantial variation in transmission risk can be useful for a more tailored risk assessment during the early phase of infection control in schools and day-care centres. Taken together, the presented innovations have potential to safe public health resources (e.g. testing) and ensure sustained education during the pandemic.
Introduction

The 2020 COVID-19 pandemic urges government leaders to define priorities when implementing anti-epidemic measures in public domains. This task requires a profound scientific basis on the beneficial and hazardous effects of these restrictions on social, economic, and health outcomes. Since the start of the colder season in the Northern Hemisphere, the number of infections with COVID-19 has started to rise again, reaching more than half a million newly reported cases globally per day in December 2020. These alarmingly high numbers have led decision makers worldwide to impose partial or complete lockdowns. In the majority of countries, these measures include the full or partial closure of educational institutions. The closure of schools and day-care centres has been one of the major debates since the start of the pandemic worldwide. Although children generally develop milder symptoms than adults or stay asymptomatic, they can become infected with COVID-19 and transmit the virus to others. At the same time, the implications of school closures are multifaceted and are considered to affect children from most deprived families the hardest, with limited access to computers and the internet as one out of several mechanisms mediating this disadvantage. Furthermore, even under the best conditions, home schooling with the parents, online teaching, TV education, or a combination thereof, are inferior learning environments as opposed to the classroom context. Besides, as schools also fulfill the task of child-care, school closures not only affect the children’s learning and mental health, but also the parents’ ability to pursue their work obligations. Similar reasoning applies to day-care facilities: taking on more child-care duties is associated with economic losses for the parents, while the transfer of child-care duties to grandparents increases the risk of COVID-19 for an older population group, which will be associated with a higher number of severe disease and eventually COVID-19-related deaths. Analysing data from August to December 2020 on routine containment measures taken by District Public Health Authorities (DPHAs) around index cases in educational institutions in Rhineland-Palatinate, Germany, this study provides urgently needed information on SARS-CoV-2 transmission risk and patterns in schools and day-care centres during a period with exponentially increasing COVID-19 population incidence.
Methods

Source population

The presented data was collected in Rhineland-Palatinate, one of the 16 Federal States of Germany with an overall population of about 4.1 million, 1492 schools, 406,607 school-children, and 144,245 children below 6 years of age in day-care.9,10 We report observations from the re-opening of educational institutions after the summer break, on August 17th, to their closure for a hard lock-down, on December 16th, 2020. During this period, publicly recommended hygiene measures in secondary schools (i.e. beginning approximately with age 10 years) in Rhineland Palatinate included (i) physical distancing (> 1·5 meters), (ii) cross- or pulse-ventilation of class-rooms before and after class, and then every 20 minutes for 5 minutes during class,11 (iii) face masks in school-buildings and “on campus”, but not in the class-room, (iv) increased frequency of surface cleaning, and (v) structural support of individual hygiene (hand, cough etiquette).12,13 On November 2nd, 2020, this concept was modified by additionally recommending face masks inside the classroom.13 Comparable recommendations existed for primary schools and day-care centres, but exempting the children from physical distancing (i) and wearing of face masks (iii).14 SARS-CoV-2 and COVID-19 are notifiable according to the German Infectious Diseases Protection Act (Infektionsschutzgesetz, IfSG), a Federal Law implemented by each Federal State’s own jurisdiction. Based hereon, physicians and laboratories have to notify COVID-19 cases to the responsible DPHA alongside with contextual information. This includes information on whether the person is a child or teacher in a school or day-care centre (§33 IfSG). From the DPHAs, information on newly identified COVID-19 cases is forwarded to one of the 16 Federal State Infectious Diseases Surveillance Centers (Landesmeldestellen), within 24 hours, and from there to the national surveillance centre at Robert Koch-Institute (RKI) in Berlin.

Origin of index cases and contact persons

Each of the 24 DPHAs in Rhineland-Palatinate is responsible for all investigations around notifiable diseases, and represent populations between 61,000 and 430,000 individuals per district. Following the identification of a COVID-19 case, qualified personnel at the competent DPHA interviews the index case, traces contacts, and initiates an active follow-up of those in category-I for fourteen days following the last contact with the index case. A category-I contact is defined as a person who either stayed face-to-face (<1·5 meters) with a COVID-19-case for
15 minutes or longer, or in the same room (i.e. irrespective of distance) for 30 minutes or longer. In the context of schools and day-care centres, the Robert Koch-Institute recommends that DPHAs classify all members of a class or group as category-I contact persons in crowded or unclear situations, or when resources at the DPHA do not allow for an individual risk assessment. Furthermore, according to current RKI guidelines, free PCR-testing is offered by the DPHAs to all category-I contact persons, irrespective of their symptom status. Depending on the DPHAs organizational structure, the testing is organized by the DPHA personnel or by external structures, such as community testing centres. In the latter case, only SARS-CoV-2 positive PCR-tests of secondary cases are notified to the DPHA, with the result that negative test results are only available to the DPHAs who organize testing themselves. This explains why DPHAs with external testing have missing information on the total number of tests done in contact persons of a given index cases, even when such testing was routinely offered to all contact persons as a standard procedure for all index cases included in this study.

Study setting and definitions
With start of the study, a 2-page questionnaire was distributed to all DPHAs, alongside with detailed instructions on inclusion and exclusion criteria for index cases and a link to upload completed questionnaires (ec.europa.eu/eusurvey). For inclusion into this study, an index case was defined as an individual that (i) tested positive for SARS-CoV-2-RNA from respiratory material, (ii) was notified as working in or attending an educational institution according to §33 IfSG, and (iii) had worked in or attended the institution for at least one day during the infectious period. The infectious period was defined as follows: (i) for symptomatic index cases as time from 2 days before to 10 days after onset of symptoms; (ii) for asymptomatic cases with unknown origin from 2 days before to 10 days after the date of taking the diagnostic swab; and (iii) for asymptomatic cases with known contact to a primary case from 3 days to 15 days after exposure.

A secondary case was defined as an individual that was identified (i) as a contact person to an index case by the competent DPHA and (ii) tested positive for SARS-CoV-2-RNA during the quarantine associated with that index case. Contact persons and secondary cases not attending the educational institution, e.g. persons living in the same household, were not to be reported in this questionnaire. Beginning with August 17th, 2020, we asked DPHAs to file one questionnaire for each eligible index case about 2 weeks after its identification, i.e. after completion of
quarantine of the contact persons. Afterwards, DPHAs received requests for contribution to SARS-S on a weekly basis, alongside interim analysis of the surveillance.

**Statistical analysis**

Assuming equal exposure time in all contact persons of a given index case, we calculated secondary attack rates (SAR, i.e. individual level risk of transmission) as the proportion of secondary cases among contact persons of a given index case, together with corresponding binomial 95% confidence intervals (95% CIs).

Associations between transmission risk on the individual level and a number of the index case’s characteristics were analysed using negative binomial regression, providing estimates of the crude incidence risk ratio (IRR) comparing the SAR in exposed and unexposed together with its 95% CI and a p-value testing H0: “both SARs are equal” (IRR=1·0). For sensitivity, we repeated these analyses based on the number of PCR-tested contacts only.

The risk of causing a SARS-CoV-2 cluster was calculated by dividing the number of index cases with at least one secondary case by the total number of index cases. To this end, we used binomial regression models estimating risk ratios (RRs) with 95% CIs and p-values testing H0: RR=1·0. Since this part of the analysis did not rely on an individual person denominator, it also included data from index cases with missing information on total number of contact persons and/or number of PCR tests done. Finally, we used negative binomial regression to estimate IRRs, their 95% CIs, and corresponding p-values for comparing the proportions of secondary cases caused by students/children and teachers, respectively. All analyses were conducted in Stata SE version 16.1 and SAS version 9.4.

**Role of the funding source**

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of this report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

**Ethical statement**

The collection, analysis and communication of the presented data take place in response to the global COVID-19 pandemic and are mandated by the German Infectious Diseases Protection Act. Ethical approval was waived by the competent ethics committee, Federal State Medical Council (Landesärztekammer) in Rhineland-Palatinate, Mainz, Germany (application no. 2021-15634-r).
Results

Source population
The course of the COVID-19 pandemic in Rhineland-Palatinate was comparable to all of Germany, with an exponential increase from the end of September (calendar week 39) until the end of October (cw43), a further growth at a lower rate (cw44–45), followed by a fluctuation on a high level of about 5000 to 7000 new cases per week (cw46–52), which equals a 7-day incidence rate of 120 to 170 per 100,000 (figure 1). Sixteen percent of the 74,733 COVID-19 cases notified in Rhineland-Palatinate in 2020 were younger than 20 years, which approximates the population proportion of 18·3% in this age group. Among these, 1,954 notifications contained contextual information on educational institutions (1,298 students/children and 684 teachers), 84% of which were notified during the study period.

Secondary attack rates (SAR)
Overall, DPHAs provided additional information for a total of 784 independent notified index cases attending an educational institution prior to diagnosis of a SARS-CoV-2 infection (591 students/children, 157 teachers, 36 unknown role). Full information on PCR-testing was available for 14,591 contact persons to 441 index cases (median 25 contacts per index case, IQR 17-40). Among these, the DPHAs identified 81 clusters with 196 PCR-positive secondary cases (SAR 1·34%, 95% CI 1·16%–1·54%) (table 1, left). Repeating the analysis based on only the 13,005 PCR-tested contacts (PCR-coverage 89%), gave an overall SAR of 1·51 (95% CI 1·30–1·73). The majority of contacts (71%) were tested between seven and ten days after their last contact with the index case (supplementary figure 1).

The SARs varied by characteristic of the index case: role (teacher > student/child, IRR=3·17, p<0·001), symptom status at time of diagnosis (pre-/asymptomatic < symptomatic, IRR=0·47, p=0·02), type of institution (day-care centres > secondary schools, IRR=3·23, p<0·001), and by age (older than 35 years > age between 6 and 21 years) (table 1, left).

Cluster level risk and cluster size
To calculate the risk of causing a cluster (i.e. the risk of transmission to at least one secondary case), we included additional 343 index cases with complete information on secondary cases, but missing information on total number of contact persons tested. In the combined dataset of overall 784 index cases, there were 130 clusters reported via the SARS-Surveillance (cluster risk 0·17, 95% CI 0·14–0·19). We observed variation in risk of causing a cluster by
characteristic of the index case (i.e. role, symptom status, type of institutions, and age) that was very similar in direction and magnitude to the comparisons based on the SARs. Index cases in dynamic groups were more likely to cause SARS-CoV-2 clusters than index cases in stable groups.

Transmission patterns by role of index case
Teacher index cases caused on average more secondary cases (169/157, risk=1·08) than students/children (145/591, risk=0·25; IRR 4·39, p<0·001). The average number of secondary cases in teachers caused by a student/child index case was 0·04 (corresponding to about one teacher secondary case in 25 student/child index cases) compared to 0·56 (one teacher secondary case in 2 teacher index cases) when the index case was also a teacher (IRR 13·25, p<0.0001). A similar comparison looking at secondary cases in children/students found a similar, but less pronounced difference towards a more likely transmission from teacher index cases to student/child secondary cases (81/157, risk=0·52) compared to transmission in educational settings among peers (120/591, risk=0·20, IRR 1·54, p<0·001). Even though our study contains about four times as many index cases in students/children as teachers (591 vs. 157), teachers caused more than three times as many secondary cases in teachers (88 vs. 25 secondary cases) (table 2). Clusters of three or more teachers among secondary cases were almost exclusively caused by teacher index cases (figure 2).

Index case, cluster size, and cluster-composition
The 329 secondary cases reported in this study occurred in 130 clusters, while the majority, 654 of overall 784 indexes (83%), led to zero secondary cases. In those 130 cases, where transmission occurred, the average cluster size was 2·5 secondary cases (supplementary figure 2). There were nine clusters reported with seven or more secondary cases (table 3), of which seven (78%) were caused by a teacher index. Seven of the large outbreaks were in day-care centres for young children, where the index cases had on average 78 category-I contacts. All nine outbreaks occurred in settings, where the index cases had a large number of category-I contacts (between 37 and 166 contacts), as opposed to an average of 33 (median 25) contacts per index case in the overall study. Larger outbreaks were more often caused by teachers (mean cluster size 3·5 vs 1·9) explaining why “black dots” prevail when moving from the lower left to the upper right corner of the grid in figure 2. Outbreaks involving several teachers follow commonly on an index case in teachers and rarely on an index in children/students, explaining why there is only a few white dots with proximity to the y-axis and clearly more white dots that
are closer to the x-axis, which measures the number of secondary cases in students/children in the grid of figure 2.

Discussion

This study provides evidence for the low transmission of COVID-19 in schools and day-care centres in the current German setting, with high incidence rates and under preventative measures. We found, that approximately 1·3% of school contacts of an index case will become SARS-CoV-2 positive. When restricting the denominator to PCR-tested contacts, we found nearly the same secondary attack rate (SAR) of 1·5%. These numbers are well in line with other published findings on risk of transmission in schools.\textsuperscript{19–24} One other study from Germany based on 87 school index cases from the DPHA of Frankfurt calculated a slightly higher but comparable SAR of 1·9%.\textsuperscript{19} Other studies from different settings in Australia, Italy, Ireland, and Singapore also report comparable SARs between 0% and 3%.\textsuperscript{20–23} Compared to students/children, the SAR was higher when the index case was a teacher. Likewise, the risk of causing a cluster and the mean number of secondary cases was higher when teachers were identified as index cases compared to students. Although not formally tested in other studies, mainly due to small sample size, descriptive findings in published literature already point towards larger numbers of secondary cases in teacher index cases and support our findings.\textsuperscript{21,25,26} In one study from the UK, half of eighteen primary school outbreaks involved teachers only.\textsuperscript{25} At the same time, we found that there is only limited transmission from child index cases to teachers, and that such events happen mainly in day-care centres: among a total of 591 student/child index cases, transmission was identified to 25 teachers: (i) thirteen children below six years of age caused 22 secondary infections in day-care teachers, (ii) while three school children caused three infections in school teachers. The fact that teachers themselves were the primary source of infection for teachers in educational institutions supports the hypothesis that professional contacts independent of teaching activities with students and children (e.g. during staff meetings, work breaks) are likely to contribute to transmission in educational institutions.

The role of asymptomatic cases in the spread of the COVID-19 pandemic has been subject of an ongoing debate. A recent review and meta-analysis found that the proportion of asymptomatic cases was 17% of all COVID-19-positive cases.\textsuperscript{27,28} They further report that the risk of transmission was about 40% lower in asymptomatic cases as compared to symptomatic cases. While this is in line with our finding of a 50% lower attack rate in contacts of
asymptomatic cases, we would like to interpret these with caution. Indeed, what we observed as ‘asymptomatic’ may in some cases just have been a PCR-diagnosis in the “pre-symptomatic” phase, e.g. in contact persons of COVID-19 positive cases outside the school/day-care setting. Hence, ‘asymptomatic’ cases in the presented study may in fact just have spent less days of their infectious period in school/day-care, thus explaining the lower risk of transmission. At the same time, these findings do not support the prevailing fear that asymptomatic cases could play a major role in the transmission of COVID-19 in schools/day-care under the current hygiene measures. One explanation for this finding, apart from shorter contact times due to ‘pre-symptomatic’ diagnosis, is a potential lower viral load in asymptomatic versus symptomatic cases.29

This study has limitations. First, we do not have a full survey of notified cases in the context of educational institutions from all sixteen reporting DPHAs. This raises the question of selection bias. However, we advised DPHAs to report consecutive index cases over at least a 4-week period or longer, thus reducing the chance of systematic under- or over-reporting of more or less salient index cases and associated under- or overestimation of transmission risk. Second, although all DPHAs routinely offer PCR tests to all contact persons to a COVID-19 index case at high-risk of transmission in the educational setting, 44% of our sample came from DPHAs that had outsourced sampling and testing to community testing centres. From these DPHAs, we received reliable information on secondary cases, but not on total contact persons and contact persons tested, since only positive test results are notifiable by testing-centres and associated laboratories. However, comparing the mean number of secondary cases between both samples shows similar results (0.39 versus 0.44 secondary cases per index case, data not shown), making us confident that these are from the same source population.

Third, the proportion of PCR tests among contact persons from DPHAs organizing testing themselves decreased in November and December, presumably as a function of increasing incidence and associated workload. However, only an estimated 20% of COVID-19 cases generally stay asymptomatic during the course of infection27 and all contact persons were monitored for disease symptoms. Thus, the 15% missing PCR tests in contact persons in November would result in 3% that could have become SARS-CoV-2 positive without being detected, making us confident that this had only minor effects on the presented results. Finally, our study attributes all transmissions in children/students and teachers detected in contact persons to COVID-19 index cases that were detected in educational settings to schools or day-care. This approach does not acknowledge that children/students and teachers may also have contact outside the institution, e.g. during leisure activities. This may have increased the
presented risk estimates, particularly for child-to-child transmission, where exposure in the classroom and during leisure commonly coincides.

In summary, we could show that on occurrence of an index case in an educational institution, the individual risk of acquiring SARS-CoV-2 as a category-I contact person is about 1·3%. This risk is significantly higher when teachers are index cases, mainly due to more common transmission between teachers. At the same time, there is lower risk of transmission between children/students, and only negligible risk for a transmission from children/students to teachers. We recommend increased attention to workplace safety in the educational setting with a focus on contact patterns between teachers in schools and day-care centres.

**Declaration of interests:** All authors, no conflicts.

**Author contributions:** The study idea, approach, and methods were conceptualised by PZ, MV, KJ, TB, and AS. PZ created the research questionnaire and the database. DH, CT, BV, SH, TK, KF, BK, SB, AM, KH, HM, AScha, and HK were responsible for the conduct of the study and for data collection. AS and PZ managed the database, verified the underlying data, performed statistical data analysis, and wrote the manuscript. AS provided the figures for the manuscript. All authors reviewed the manuscript, provided input, and approved the final version

**Data sharing:** Data and analytic code used for this study will be shared with researchers immediately following the publication upon request from the corresponding author.
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Table 1: Risk of COVID-19 transmission in educational settings, by characteristic of the index case, Rhineland-Palatinate, Germany, 2020

| Characteristic of index case | Risk of transmission on individual level (SAR), N=441 | Risk of transmission on cluster level (≥ 1 secondary case), N=784 |
|-----------------------------|-----------------------------------------------------|-----------------------------------------------------|
|                             | Index cases* | SAR (%) [95%CI] | Crude IRR [95%CI] | P-value | Index cases* | Clusters (secondary cases) | Mean cluster size | Risk [95%CI] | Crude RR [95%CI] | P-value |
| Role                        |             |                 |                   |         |             |                  |                      |             |                   |         |
| Student/child               | 346         | 10716           | 87.47             | 0.92 [0.75–1.12] | 1.00     | ref           |                       |               |                   |         |
| Teachers                    | 75          | 2858            | 92.93             | 3.18 [2.57–3.90] | 3.17 [1.79–5.59] | <0.001 |               |               |                   |         |
| unknown                     | 20          | 6 (1017)        | 95.97             | 0.59 [0.22–2.45] | 0.77 [0.23–2.63] | 0.68   |               |               |                   |         |
| Symptom status              |             |                 |                   |         |             |                  |                      |             |                   |         |
| Symptomatic                 | 300         | 10566           | 88.11             | 1.57 [1.34–1.83] | 1.00     | ref           |                       |               |                   |         |
| Asymptomatic                | 127         | 3523            | 91.26             | 0.60 [0.37–0.91] | 0.47 [0.25–0.89] | 0.02   |               |               |                   |         |
| unknown                     | 14          | 9 (502)         | 95.62             | 1.79 [0.82–3.38] | 1.34 [0.37–4.85] | 0.65   |               |               |                   |         |
| Type of institution*        |             |                 |                   |         |             |                  |                      |             |                   |         |
| Day-care (0-6 years)        | 99          | 4392            | 90.64             | 2.50 [2.06–3.01] | 3.23 [1.76–5.91] | <0.001 |               |               |                   |         |
| Primary Schools             | 88          | 2375            | 85.64             | 1.13 [0.75–1.64] | 1.62 [0.80–3.31] | 0.18   |               |               |                   |         |
| Secondary Schools           | 173         | 4125            | 90.08             | 0.69 [0.49–0.93] | 1.00     | ref           |                       |               |                   |         |
| Vocational Schools          | 52          | 1181            | 84.17             | 0.42 [0.14–0.99] | 0.65 [0.21–1.99] | 0.45   |               |               |                   |         |
| Other/unknown               | 29          | 13 (659)        | 91.96             | 1.97 [1.05–3.35] | 2.99 [1.12–7.98] | 0.03   |               |               |                   |         |
| Age                         |             |                 |                   |         |             |                  |                      |             |                   |         |
| 0-5 years                   | 42          | 31 (1828)       | 90.43             | 1.70 [1.16–2.40] | 1.29 [0.55–3.03] | 0.55   |               |               |                   |         |
| 6-10 years                  | 89          | 15 (2410)       | 82.53             | 0.62 [0.35–1.02] | 0.72 [0.32–1.63] | 0.43   |               |               |                   |         |
| 11-15 years                 | 113         | 25 (3358)       | 89.93             | 1.04 [0.73–1.45] | 1.00     | ref           |                       |               |                   |         |
| 16-20 years                 | 90          | 17 (2884)       | 88.04             | 0.59 [0.34–0.94] | 0.56 [0.25–1.24] | 0.15   |               |               |                   |         |
| 21-34 years                 | 42          | 30 (1321)       | 88.19             | 2.27 [1.54–3.23] | 1.97 [0.84–4.64] | 0.12   |               |               |                   |         |
| 35 years and older          | 45          | 62 (1773)       | 93.80             | 3.50 [2.69–4.46] | 2.80 [1.27–6.20] | 0.01   |               |               |                   |         |
| unknown                     | 20          | 6 (1017)        | 95.97             | 0.59 [0.22–1.88] | 0.65 [0.18–2.35] | 0.51   |               |               |                   |         |
| Type of groups              |             |                 |                   |         |             |                  |                      |             |                   |         |
| Stable Groups               | 313         | 80 (8560)       | 88.15             | 0.92 [0.73–1.15] | 1.00     | ref           |                       |               |                   |         |
| Dynamic Groups              | 111         | 25 (540)        | 90.90             | 1.68 [1.35–2.05] | 1.45 [0.84–2.02] | 0.18   |               |               |                   |         |
| unknown                     | 17          | 25 (511)        | 86.89             | 0.89 [0.39–1.94] | 3.21 [1.07–9.59] | 0.04   |               |               |                   |         |
| Sex                         |             |                 |                   |         |             |                  |                      |             |                   |         |
| Female                      | 194         | 66 (338)        | 88.86             | 1.14 [0.88–1.44] | 1.00     | ref           |                       |               |                   |         |
| Male                        | 241         | 128 (4755)      | 89.32             | 1.50 [1.25–1.78] | 0.78 [0.46–1.31] | 0.35   |               |               |                   |         |
| unknown                     | 6           | 2 (228)         | 89.04             | 0.66 [0.11–3.13] | 0.64 [0.07–5.67] | 0.69   |               |               |                   |         |
| Month of infection           |             |                 |                   |         |             |                  |                      |             |                   |         |
| August                      | 33          | 6 (909)         | 97.36             | 0.66 [0.24–1.43] | 1.00     | ref           |                       |               |                   |         |
| September                   | 78          | 9 (2548)        | 97.84             | 0.35 [0.16–0.67] | 0.45 [0.12–1.78] | 0.26   |               |               |                   |         |
| October                     | 95          | 84 (3986)       | 93.15             | 2.11 [1.68–2.60] | 1.92 [0.58–6.42] | 0.29   |               |               |                   |         |
| November                    | 151         | 74 (4920)       | 85.28             | 1.65 [1.30–2.06] | 1.77 [0.55–5.75] | 0.34   |               |               |                   |         |
| December                    | 84          | 23 (2656)       | 78.43             | 0.87 [0.55–1.30] | 1.11 [0.32–3.91] | 0.87   |               |               |                   |         |
| Total                       | 441         | 196 (14591)     | 89.13             | 1.34 [1.16–1.54] | n.a.     | n.a.          |                       |               |                   | n.a.   |

n.a. = not available

Crude IRR = Crude Incidence Rate Ratio

95%CI = 95% Confidence Interval
Left side of table displays secondary attack rates (SARs), defined as the proportion of secondary cases in all contact persons. Incidence risk ratios (IRRs) and corresponding confidence intervals (CIs) and p-values from negative binomial regression compare the SARs between different groups. The right side of the table displays the cluster risk, i.e. the risk of causing at least one secondary infection, and associated risk ratios (RRs) from binomial regression for the comparison between groups. *Index cases with information on number of contact persons and number of PCR tests, bcomplete study population, cincludes teachers.

Table 2. COVID-19 transmission between students/children and teachers, Rhineland-Palatinate, Germany, 2020 (N=748)*

| Transmission from | to all types of secondary cases (n=314) | to student/child (n=201) | to teachers (n=113) |
|------------------|----------------------------------------|--------------------------|---------------------|
|                   | N cases (clusters) | Riskb | IRR [95% CI]c | P-valuec | N cases (clusters) | Riskb | IRR [95% CI]c | P-valuec | N cases (clusters) | Riskb | IRR [95% CI]c | P-valuec |
| student/child, n=591 | 145 (76) | 0·25 | 1·00 | <0·001 | 120 (70) | 0·20 | 1·00 | <0·001 | 25 (16d) | 0·04 | 1·00 | <0·001 |
| teachers, n=157    | 169 (48) | 1·08 | 4·39 [2·67–7·21] | 0·041 | 81 (37) | 0·52 | 2·54 [1·52–4·23] | 0·001 | 88 (32) | 0·56 | 13·25 [6·59–26·67] | 0·001 |

Table displays the mean number of secondary cases (total – student/child –teachers) conditional on the role of the index case. The mean number of secondary cases in teachers are 0·04 and 0·56 for child and teacher index cases, respectively, corresponding to an IRR of 13·3. *36 index cases with missing age/role information, bmean number of new cases per index case, cIncidence Risk Ratios (IRRs) and corresponding confidence intervals (CIs) and p-values from negative binomial regression, dindex cases were (i) thirteen children <6 years of age in day-care associated with 22 teachers and (ii) 3 children/students ≥ 6 years of age in schools associated with 3 teachers.
Table 3: Specific information on the nine largest clusters in our study (size ≥ 7)

| Cluster | Month of Symptom Onset | Role of Index | Age group of Index | Type of Institution | Number of high risk contacts\(^b\) | Number of Secondary Cases |
|---------|------------------------|---------------|-------------------|---------------------|---------------------------------|--------------------------|
|         |                        |               |                   |                     | Total | % PCR-tested | Total | Children | Teachers |
| 1       | December               | Teacher       | 41-45             | Day-care ≤ 6 years  | 43    | Unknown      | 8     | 3        | 5        |
| 2       | October                | Child         | 0-5               | Day-care ≤ 6 years  | 150   | 70%          | 9     | 7        | 2        |
| 3       | December               | Teacher       | 41-45             | Day-care ≤ 6 years  | 45    | Unknown      | 10    | 5        | 5        |
| 4       | November               | Teacher       | 41-45             | Day-care ≤ 6 years  | 79    | 86%          | 10    | 8        | 2        |
| 5       | October                | Teacher       | 21-25             | Day-care ≤ 6 years  | 87    | 85%          | 10    | 3        | 7        |
| 6       | November               | Teacher       | 16-20             | Day-care ≤ 6 years  | 37    | Unknown      | 10    | 3        | 7        |
| 7       | October                | Teacher       | 51-55             | Day-care ≤ 6 years  | 106   | 95%          | 15    | 5        | 10       |
| 8       | October                | Child         | 11-15             | Secondary school    | 166   | 100%         | 7     | 7        | 0        |
| 9       | November               | Teacher       | 46-50             | Unknown             | 56    | Unknown      | 7     | 0        | 7        |

\(^a\)Date of symptom onset for symptomatic cases, date of test for asymptomatic cases, \(^b\)High risk defined as person who stayed face to face (<1·5 meters) for 15 minutes or longer, or in the same room for 30 minutes or longer with a COVID-19-case, respectively. In crowded or unclear situations, or when resources do not allow for an individual risk assessment, particularly in the context of schools and day-care centres, all members of a class or group may be classified as high risk contact persons.
Figure legends

Figure 1: Age-stratified course of the COVID-19 pandemic in Rhineland-Palatinate, Germany, 2020. Figure displays number (%) of SARS-CoV-2 cases notified in the Federal State of Rhineland-Palatinate by calendar week, overall, and among subjects ≤ 20 years of age.

Figure 2: Frequency of secondary cases in children and teachers by role of the index case. Graph displays frequency and role of 784 index cases and their association with secondary transmission to teachers and students/children in schools and day-care centres in Rhineland-Palatinate, Germany, 2020. Grid position of circles represent the number of secondary cases in students/children (x-axis) and teachers (y-axis). The circle size is proportional to the number of index cases with the respective number of secondary cases reported in this study. The colour inside the circle represents the share of children (white) and teachers (black) observed among index cases represented by that circle. Circles in areas of the grid with same shade of grey represent clusters of similar size. For instance, the black dot at the very top of the grid identifies one cluster of size 15 (high cluster size = dark shade of grey) that emerged from a teacher index case (indicated by black colour vs. white colour of dot) and produced 10 secondary cases in teachers (position on y-axis) and 5 in student/children (position on x-axis).
Number of COVID-19 positive individuals in Rhineland-Palatinate, Germany

Study Period

- Left axis: cases <20 years
- Left axis: cases ≥20 years
- Right axis: % of cases <20 years
- Right axis: % of population <20 years

Number of cases vs calendar week 2020
Supplementary Figure 1: Timing of PCR testing in contact persons

Median time 7 days (Interquartile range: 6-9 days), 1.5% with missing information
The median cluster size in those index cases who caused at least one secondary case was 1 (inter quartile range 1 to 3, minimum 1, maximum 15).
# STROBE Statement—checklist of items that should be included in reports of observational studies

| **Item No** | **Recommendation** | **Page No** |
|-------------|--------------------|-------------|
| **Title and abstract** |  |  |
| 1 | (a) Indicate the study’s design with a commonly used term in the title or the abstract | 1 |
|  | (b) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** |  |  |
| 2 | Explain the scientific background and rationale for the investigation being reported | 3-5 |
| **Objectives** | 3 | State specific objectives, including any prespecified hypotheses | 5 |
| **Methods** |  |  |
| 4 | Present key elements of study design early in the paper | 1, 6-7 |
| 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 6-7 |
| 6 | (a) **Cohort study**—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up  
**Case-control study**—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls  
**Cross-sectional study**—Give the eligibility criteria, and the sources and methods of selection of participants | 6-7 |
|  | (b) **Cohort study**—For matched studies, give matching criteria and number of exposed and unexposed  
**Case-control study**—For matched studies, give matching criteria and the number of controls per case | -- |
| 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 7-8 |
| 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 7-8 |
| **Bias** | 9 | Describe any efforts to address potential sources of bias | 8, 12 |
| **Study size** | 10 | Explain how the study size was arrived at | 7, 9 |
| **Quantitative variables** | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 8 |
| **Statistical methods** | 12 | (a) Describe all statistical methods, including those used to control for confounding  
(b) Describe any methods used to examine subgroups and interactions  
(c) Explain how missing data were addressed  
(d) **Cohort study**—If applicable, explain how loss to follow-up was addressed  
**Case-control study**—If applicable, explain how matching of cases and controls was addressed  
**Cross-sectional study**—If applicable, describe analytical methods taking account of sampling strategy | 8, 8, 8, 16, -- |
(e) Describe any sensitivity analyses

| Results | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed |
|---------|-----|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|         |     | (b) Give reasons for non-participation at each stage |
|         |     | (c) Consider use of a flow diagram |
|         | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders |
|         |     | (b) Indicate number of participants with missing data for each variable of interest |
|         |     | (c) Cohort study—Summarise follow-up time (eg, average and total amount) |
|         | 15* | Cohort study—Report numbers of outcome events or summary measures over time |
|         |     | Case-control study—Report numbers in each exposure category, or summary measures of exposure |
|         |     | Cross-sectional study—Report numbers of outcome events or summary measures |
|         | 16  | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included |
|         |     | (b) Report category boundaries when continuous variables were categorized |
|         |     | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period |
|         | 17  | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses |

**Discussion**

| Key results | 18  | Summarise key results with reference to study objectives |
|-------------|-----|--------------------------------------------------------|
| Limitations | 19  | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias |
| Interpretation | 20  | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence |
| Generalisability | 21  | Discuss the generalisability (external validity) of the study results |

**Other information**

| Funding | 22  | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.