Impact of school closures and re-openings on COVID-19 transmission

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Abstract

Background: Globally, the education of students at primary and secondary schools has been severely disrupted by the implementation of school closures to reduce the spread of coronavirus disease 2019 (COVID-19). The effectiveness of school closures in reducing transmission of COVID-19 and the impact of re-opening schools are unclear.

Methods: Research criteria for this rapid review included empirical studies, published or pre-published worldwide before January 25, 2021, that assessed the effectiveness of school closures in reducing the spread of COVID-19 and the impact of school re-openings on COVID-19 transmission.

Results: Twenty-four studies on the impact of school closures and re-openings on COVID-19 transmission were identified through the seven databases that were searched. Overall the evidence from these studies was mixed and varied due to several factors such as the time of implementation of public health measures, research design of included studies and variability among the levels of schooling examined.

Conclusion: Preliminary findings suggest that school closures have limited impact on reducing COVID-19 transmission, with other non-pharmaceutical interventions considered much more effective. However, due to the limitations of the studies, further research is needed to support the use of this public health measure in response to the COVID-19 pandemic.

Introduction

As of March 11, 2020, the World Health Organization has declared the coronavirus disease 2019 (COVID-19) outbreak a pandemic (1). Globally, jurisdictions started to implement a variety of non-pharmaceutical interventions (NPIs) to limit the spread and the impact of COVID-19 disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Closing schools was one of the NPIs implemented; however, these closures not only disrupted the education and daily routines of students, but also the lives of teachers and parents.

While school closures have been implemented to combat the spread of COVID-19, they were also associated with negative effects on student's mental health and academic progress and lead to increased stress in parents and teachers (2). With a lack of school-based peer interactions and daily routines, it has been reported that students experience increased distress, loneliness, anxiety and depressive symptoms (2,3). School routines are crucial for maintaining the well-being of students, especially

those with mental health or special education needs (4). In addition, school closures have been associated with reduced academic achievement due to delayed educational progress (3,5,6). It is uncertain whether virtual learning is equally effective and many students from low-income households lack access to, and accommodations with, online materials (6).

Given the negative impacts of school closures, it is important to consider whether they are significantly effective in reducing the impact of COVID-19. Initially, it was assumed that school closures would be effective in mitigating the spread of COVID-19 based on the evidence from both seasonal and epidemic influenza (7,8). In contrast, modelling studies conducted in Ontario and across Canada during the first and second waves found that school closures had limited impact on reducing the transmission of COVID-19 compared with other NPIs (9–11). Other modelling studies reported modest effects of school closures in delaying peak case numbers early in the pandemic (12,13), while some

studies showed a smaller magnitude of effect when compared with other NPIs (14,15). Early modelling studies relied on the underlying assumption that there is a low transmission risk in children. Although modelling studies are excellent for making informed predictions, their accuracy is dependent on the assumptions and the quality of data used. Overall, there was a need to assess the potential impacts of school closures in reducing the spread of COVID-19.

This review summarizes empirical studies on the effectiveness of school closures and the impact of re-opening schools in reducing community transmission of COVID-19 and decreasing the incidence of COVID-19 in primary and secondary schools. The principal focus of this article was the impact of primary and secondary school closures, although if studies also included data from other types of schools this was included as well.

Methods

Our research criteria included empirical studies that assessed the impact of school closures and/or re-openings on COVID-19 that were published before January 25, 2021. Predictive modelling studies were excluded. Searches to retrieve relevant articles were conducted in PubMed, Scopus, BioRxiv, MedRxiv, ArXiv, SSRN and Research Square, by the Emerging Science Group of the Public Health Agency of Canada. Search terms included the following: school AND closure OR re-opening within a database of COVID-19 literature that is updated daily. References were also used to search for additional relevant studies. Included literature was confined to English and French languages. Articles (n=966) were then screened for relevance. A total of five observational studies and nineteen ecological studies were found to be relevant (see **Appendix Table A1** and **Table A2**).

Results

Twenty-four articles published prior to January 25, 2021 on the impact of school closures and/or re-openings on the spread of COVID-19, were identified. These included a cross-sectional study (16), two cohort studies (17,18), two cluster and outbreak investigations (19,20) and 19 ecological studies. Eleven of these studies are preprints or studies that have not yet been peer-reviewed. All studies identified in this review pre-date the identification of variants of concern.

Most observational studies assessing the impact of school closures/re-openings on the spread of COVID-19 in schools reported no significant effects (see Appendix Table A1). Four studies found no difference in incidence of cases both before and after closing schools for the holidays, following children who stayed at home vs those who went to school with strict surveillance, or following school re-opening (16–19). An outbreak investigation study reported a large outbreak from a high school in Israel, but this was confounded by the fact that the

mask mandate was lifted just as there was a heatwave, which may have affected compliance with other recommended public health measures (20). Furthermore, it was noted that there was overcrowding in the high school that limited physical distancing, and extracurricular activities were not banned.

Of the ecological studies assessing community transmission (see Appendix Table A2), ten were conducted across multiple countries, five in the United States, two in Asia and two in Europe. Five studies reported that school closures and re-openings were not significantly associated with reduction in the transmission and incidence of COVID-19 and were much less effective in reducing transmission when compared with other NPIs (21–25). Four studies reported a reduction in the incidence of COVID-19 in the community ranging from 8% to 62% following school closures (26–29). Other studies reported a significant reduction in the effective reproduction number (R_t) (30–32). Three studies attributed significant reductions in mortality to school closures (29,33,34) and one study reported increased mortality with delayed school closures (35).

Discussion

Overall, the evidence from these studies was mixed and varied due to several factors. Based on the findings of the observational studies assessing the incidence of COVID-19 in schools, school closures and re-openings did not significantly contribute to COVID-19 transmission when infection prevention and control measures (IPAC) were implemented in schools. The IPAC measures implemented by the schools were similar across most of the observational studies and included masks, physical distancing, frequent cleaning, reduced class sizes and improved hand hygiene. The implementation of these measures in schools have been reported to act as a mediating variable because of the reduced transmission and risk of infection with IPAC measures (36).

The findings from the ecological studies assessing community transmission were inconsistent, with some studies reporting that school closures/re-openings were not significantly associated with reduction in transmission (21–25), and other studies reporting a significant reduction in R_t (30–32) and mortality (29,33,34). In several of these ecological studies, it was reported that other NPIs such as lockdowns, gathering bans, mask mandates, non-essential business closure and travel restrictions were more effective than school closures in reducing the transmission of COVID-19. Ecological studies are considered a low level of evidence due to the research design, the multiple confounding factors and the high degree of variability in the results. All of the ecological studies included in this review analyzed data on school closures/re-openings early in the pandemic, between January–August 2020, when multiple NPIs were implemented simultaneously. Therefore, it was not possible to isolate the impact of school closures/re-openings on the

number of cases of COVID-19 in the community. Additionally, only one of the ecological studies described if there was adherence to IPAC measures in the schools (25). These factors likely contribute to the heterogeneity between studies.

An important limitation of this review was the inconsistencies in the levels of schooling that were included in each study, which may have increased the variability in measures of how effective school closures were across studies. Most studies did not provide information on what schools were included when determining the impact of school closures on the spread of COVID-19. Some studies measured primary and secondary school closures alone and some measured them in combination with post-secondary schools. The risk of transmission may have varied significantly between students in primary and secondary schools because of potential differences in their behaviours and adherence to IPAC measures with resultant difference in reduction of viral transmission. Transmission was found to be lower in primary schools relative to secondary schools, based on the results of one study in a review that assessed this (19). Although not specifically stated in the previous study, their results were in line with what we know about the use of IPAC to limit transmission in these settings (37). Additionally, the relative impact of school closures and re-openings have been shown to vary according to the time of implementation, level of community transmission, and the structure of populations from different countries.

Based on the empirical evidence summarized in this article, school closures had a small effect on limiting the spread of COVID-19 in schools and the community and appeared to be much less effective than other NPIs. These findings are also consistent with modelling studies conducted across Canada (9–15). The implementation of school closures is currently based on when the transmission of COVID-19 in the community is high—as dictated by local health jurisdictions; however, the role of school closures and re-opening in areas with low community transmission is less clear and should be studied further.

School closures may be associated with negative effects on student's mental health and academic progress (2); thus, public health decision makers should consider if the apparent low efficacy of school closures in reducing transmission outweighs the many negative consequences on students' well-being. Overall, the confidence in this evidence is low given that the studies in this review vary by several factors and were conducted at different times and in a number of countries. Finally, the study period of this review is also a limitation, as there are marked differences in the 3rd and 4th waves compared with the 1st and 2nd waves of COVID-19 with the introduction of more transmissible variants of concern. How the present evidence will compare with that obtained during periods of the spread of more transmissible variants of concern is not known at this time and will require further study.

Conclusion

The findings of this review may have implications for public health decision making and future research on mitigation strategies for schools. The preliminary evidence provided in this review suggests that school closures and re-openings may have only a limited impact on the transmission of COVID-19 within a community. However, there is still a high degree of uncertainty due to the high variation in the methodology and results across the various studies. Additional research is needed to further explore more systematically the impacts of school closures and to determine how and when they may be used most effectively in controlling the epidemic.

Important knowledge gaps to consider are how 1) the presence of new variants of concern and 2) the rollout of COVID-19 vaccinations will impact the transmission of COVID-19 within the schools and communities. The evidence presented in this article pre-dates the introduction of variants of concern; therefore, additional research is needed to understand how the emergence and spread of these variants will impact the effectiveness of school closures or what the impact of school re-openings will have on the spread of COVID-19.

Authors' statement

Competing interests

None.

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Appendix: Tables

Appendix Table A1: Summary of observational studies assessing the impact of school closures or re-openings on the transmission of COVID-19 in schools and the community (n=5)

Study	Method	Key outcomes
Cohort studies (n=2)		
Gandini (2020) (17) Prospective cohort study and cross-sectional study Italy Sep–Nov 2020	This study analyzed the association between school re-opening dates and COVID-19 cases across twenty-one Italian regions by using a database on positive cases in elementary, middle and high schools and SARS-CoV-2 incidence in the general population. IPAC measures included temperature control, hand hygiene, mask mandate for students/staff, physical distancing, ban on sports and music and reduced duration of school. Several COVID-19 outcomes were measured during school re-openings: growth of incidence, R_t, and secondary infections.	There was no evidence that the second SARS-CoV-2 wave was driven by school re-openings across the regions. SARS-CoV-2 incidence among students was lower than the general population of all but two Italian regions. The increase in R_t was not associated with the different school opening dates. School closures implemented in two regions did not affect the decline of R_t.
Fontanet (2020) (18) Retrospective cohort study France Feb–Apr 2020	This retrospective cohort study included primary school pupils, teachers, non-teaching staff, parents and relatives exposed to SARS-CoV-2 in February and March from six schools. IPAC measures were not described. A questionnaire covering sociodemographic information and history of recent symptoms was completed by participants. Blood samples were also tested for the presence of anti-SARS-CoV-2 antibodies using a flow-cytometry-based assay. Three introductions of SARS-CoV-2 occurred prior to school closures. Spread within schools vs families was investigated in this sero-epidemiological study. IAR was compared between school contacts and family contacts to understand the potential impact of the school closure.	IAR was 45/510 (8.8%), 3/42 (7.1%), 1/28 (3.6%), 76/641 (11.9%) and 14/119 (11.8%) among primary school pupils, teachers, non-teaching staff, parents and relatives, respectively (p=0.29). No secondary infections from COVID-19 introductions in schools was detected among students and teachers. Among pupils who were infected, their parents were significantly more likely to be infected (61.0% versus 6.9%; p<0.0001), The same was identified among relatives of infected pupils compared with non-infected pupils (44.4% versus 9.1%; p=0.002). Transmission did not appear to be impacted by the closure of schools.
Cross-sectional studies (n=1)		
Kriger (2020) (16) Cross-sectional study Israel Mar–May 2020	During a national lockdown, an alternative school was used for healthcare workers' children to attend with strict symptom surveillance. Families with children who remained at home were compared with children at this alternative school. IPAC measures in the school included daily disinfecting, face mask use by staff and frequent hand washing. This cross-sectional study included 70 children who attended the alternative primary school and 36 who stayed home, along with their 78 parents. Data was collected through a short questionnaire; nasopharyngeal and oropharyngeal swabs were obtained and tested for SARS-CoV-2 by RT-PCR, and blood was collected for SARS-CoV-2 IgA and IgG titres.	Symptoms were reported in approximately 16% of children in both groups: those who attended the school (n=11/70) and those who did not (n=6/36). Positive serology tests showing previous exposure was detected in less than 2% of each group and they were not significantly different from each other. There was no evidence of increased infection in those at school compared with those at home.
Cluster and outbreak investigations (n=2)		
Larosa (2020) (19) Cluster investigation Italy Sep–Oct 2020	This cluster investigation analysed the transmission of COVID-19 in 41 classes of 36 schools upon their re-opening in northern Italy. The secondary attack rate was measured in students and teachers in elementary and secondary schools (middle and high schools). IPAC measures included: mask mandate for high school students only, physical distancing and ban of extracurricular activities.	Secondary attack rate for COVID-19 was reported to be higher in secondary schools (6.6%) than in elementary schools (0.38%).
Stein-Zamir (2020) (20) Outbreak investigation Israel May–Jun 2020	This outbreak investigation study assessed the epidemiological characteristics of a high school outbreak in Jerusalem that displayed mass COVID-19 transmission upon school reopening on May 17. The high school included grades 7–12. An extreme heatwave occurred upon the re-opening of the school. IPAC measures: face mask use was lifted for three days during the heatwave, physical distancing was below the standard in overcrowded classes, and extracurricular activities were not banned.	It was reported that the proportion of the 10–19 year-olds was 19.8% (n=938/4,747) of the cases before May 24th, and then increased to 40.9% (n=316/772) after May 24th. Testing of the whole school revealed that 153 students (attack rate: 13.2%) and 25 staff members (attack rate: 16.6%) were COVID-19 positive. COVID-19 rates were higher in students in grades 7–9 than in grades 10–12.

Abbreviations: COVID-19, coronavirus disease 2019; IAR, infection attack rate; IgA, immunoglobulin A; IgG, immunoglobulin G; IPAC, infection prevention and control; R_t, effective reproduction number; RT-PCR, reverse transcription polymerase chain reaction; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2

Appendix Table A2: Summary of ecological studies assessing the effectiveness of school closures or re-openings on reducing spread of COVID-19 in the community (n=19)

Study	Method	Key outcomes
Global (n=10)		
An (2021) (21) Ecological study Global Jan–Jul 2020	This study aimed to identify associations between six NPIs and the number of COVID-19 infections. Using worldwide data on NPIs and COVID-19 infections between Jan–Jul 2020, analysis was conducted on the short- and long-term effects of NPIs on new infection rates five, nine, 12, and 21 days after their adoption. IPAC measures and level of schooling included in the study were not described. NPIs examined included mask mandates, international travel restrictions, domestic lockdowns, mass gathering bans, restaurant closures and school closures.	School closures took more time than other NPIs to show efficacy. After a time lag, the impact of school closures on new case rates was -0.492 (SE=0.16) at 12 days ($p<0.01$), -0.722 (SE=0.148) at 21 days ($p<0.001$), and -0.824 (SE=0.0967) at 30 days ($p<0.001$). School closures were not found to have significant effects on population-adjusted infections in the long-term (90th to 120th day).
Banholzer (2020) (27) Ecological study 20 countries Apr 2020	In this study, the impact of NPIs on the relative reduction of new COVID-19 cases using a Bayesian hierarchical model with a time-delayed effect for each NPI. IPAC measures were not described. NPIs examined included 1) primary school closures, 2) border closures, 3) public event bans, 4) gathering bans, 5) venue closures, 6) lockdowns prohibiting public movements without valid reason and 7) work bans on non-essential business activities.	The mean reduction of new COVID-19 cases with primary school closures was 8% (95% CI: 0%–23%). Compared with other NPIs examined, school closures appeared to be one of the least effective NPIs.
Banholzer (2021) (26) Ecological study 20 countries Feb–May 2020	Using a semi-mechanistic Bayesian hierarchical model, this study aimed to measure the effectiveness of seven NPIs in reducing the number of new infections. IPAC measures were not described. NPIs examined included 1) primary school closures, 2) border closures, 3) public event bans, 4) gathering bans, 5) venue closures, 6) lockdowns prohibiting public movements without valid reason and 7) work bans on non-essential business activities.	The relative reduction of new COVID-19 cases with primary school closures was 17% (95% CI: 2%–36%). This reduction was lower than two other NPIs (event bans and venue closures).
Brauner (2021) (28) Ecological study 41 countries Jan–May 2020	This study estimated the effectiveness of NPIs in 41 countries using a Bayesian hierarchical model by linking intervention implementation dates to national case and death counts. Intervention effect sizes were categorized by the median reductions in the R_t of less than 17.5% (small), between 17.5 and 35% (moderate) and at least 35% (large). NPIs examined included: limiting gatherings to fewer than 1,000 or fewer than 100 or fewer than 10, closing some businesses, closing most businesses, closing schools and universities, and stay at home orders. IPAC measures were not described.	The percentage reduction in R_t associated with closing both schools and universities in conjunction was 38% (95% CI: 16%–54%), which was categorized as a large effect size. The individual effects of school closures was not measured.
Klimek-Tulwin (2020) (38) Ecological study Global Mar 2020	This study aimed to assess the effect of school closures on COVID-19 cases globally by measuring correlation between the incidence rate on the day of school closure and the incidence rate in the following days. IPAC measures and level of schooling included in the study were not described.	The results indicate that there was a strong correlation between the day of educational facilities closure and the incidence rate in the following days (16th ($p=0.004$), 30th ($p=0.002$) and 60th ($p=0.031$) days since the 100th confirmed case in each country). Early closure of schools is statistically significantly correlated with lower incidence rates further on during the different phases of the epidemic.
Papadopoulos (2020) (39) Ecological study Global Jan–Apr 2020	The impact of lockdown measures was assessed globally using publicly available data. The timing and association of early NPIs with $\log_{10}$ national deaths (Log_D) and $\log_{10}$ national cases (Log_C) was compared between nations. IPAC measures and level of schooling included in the study were not described.	Early generalized school closure ($p=0.050$, regression coefficient ß=-0.012, 95% CI: 0%–-0.024%) was associated with reduced Log_C ($\log_{10}$ national cases).
Pasdar (2020) (34) Ecological study 22 countries May 2020	The aim of this study was to determine the associations between NPIs and COVID-19 outcomes. Associations with NPIs were assessed with their respective stringency index on several outcomes that form the epidemic curve: mean mortality rate, time to peak, peak deaths per 100,000 population, cumulative deaths after peak per 100,000 population and ratio of the mean slope of the descending curve to the mean slope of the ascending curve. IPAC measures and level of schooling included in the study were not described.	School closures were effective against all outcomes, except time to reaching the peak of the epidemic curve. The strongest association was seen in cumulative deaths after peak, per 100,000 (rs=-0.744, $p=0.009$). In non-European countries, school closures were most effective against mean mortality rate (rs=-0.757, $p=0.049$).
Esra (2020) (30) Ecological study Global Jan–May 2020	This study used globally reported data on SARS-CoV-2 cases to fit a Bayesian model framework to estimate the association with NPIs and transmission. NPIs examined include stay home mandates, gathering limits, school closures (primary, secondary and tertiary educational institutions) and mask policies. IPAC measures were not described.	There was an estimated mean reduction in R_t of 12% (95% CI: 5%–19%) with school closures (primary, secondary and tertiary educational institutions).

Appendix Table A2: Summary of ecological studies assessing the effectiveness of school closures or re-openings on reducing spread of COVID-19 in the community (n=19) (*continued*)

Study	Method	Key outcomes
Global (n=10) (*continued*)		
Jüni (2020) (40) Ecological study Global Mar 2020	This prospective study of geopolitical areas aimed to determine whether climate or public health interventions are associated with reducing transmission of COVID-19. A weighted random effects regression was used to determine the association between epidemic growth RRR and climate measures and public health interventions such as school closures, restrictions of mass gatherings and measures of social distancing during an exposure period 14 days previously. IPAC measures and level of schooling included in the study were not described.	Strong negative associations with epidemic growth were found for school closures (RRR - 0.63, 95% CI: 0.52%–0.78%). This association was more pronounced in areas that implemented two or three NPIs compared with one NPI.
Stokes (2020) (33) Ecological study Global Jun 2020	This study examined the variation of NPIs in 130 countries in two periods: 1) prior to first COVID-19 death and 2) 14-days-post first COVID-19 death. This study examined associations with daily COVID-19 deaths per million and each 24 day period (time between virus transmission and mortality). IPAC measures and level of schooling included in the study were not described.	Stricter/earlier school closures were associated with the largest reductions in COVID-19 deaths (-1.23 per million [95% CI: -2.20%–-0.27%]) compared with other NPIs.
North America (n=5)		
Auger (2020) (29) Ecological study US Mar–May 2020	This study aimed to determine if school closures were associated with a decrease in the cumulative incidence of COVID-19 and mortality. The impact of primary and secondary school closures was assessed using publicly available data from all 50 states. IPAC measures were not described.	Results showed that school closures were associated with a significant decline in incidence of COVID-19 (-62% [95% CI: -71%–-49%]) and in mortality (-58% [95% CI: -68%–-46%]). These associations were stronger in states with a low cumulative incidence of COVID-19 at the time of the school closure.
Dreher (2020) (31) Ecological study US Apr 2020	This study aimed to measure the impact of NPIs on the effective R_t of COVID-19 in US states. The average R_t was measured during the weeks after each state reached 500 cases. R_t was measured at the week immediately following 500th case (days +1 to +7) and at a one-week delay from 500th case (days +8 to +14). NPIs examined included stay at home order, educational facilities closure and non-essential business closure. IPAC measures and level of schooling included in the study were not described.	Educational facilities closure was associated with a significant reduction in R_t compared with states without this policy the week following 500 cases (ß=-0.17, 95% CI: -0.30%–-0.05%, *p*=0.009). From days 8 to 14 after the 500th case date, educational facilities closure was associated with a significant reduction in R_t compared with controls (ß=-0.12, 95% CI: -0.21%–-0.04%, *p*=0.006).
Krishnamachari (2020) (41) Ecological study US May 2020	This study aimed to examine the effects of NPIs on the cumulative incidence rates of COVID-19 in the US on a state-level in the 25 most populated cities, while adjusting for socio-demographic risk factors. A negative binomial regression was used to calculate adjusted rate ratios by comparing two levels of a binary variable: "above median value," and "median value and below" for days to implementing an NPI. NPIs assessed in this study included: days to closing of non-essential businesses, days to stay home orders, days to restrictions on gatherings, days to restaurant closings and days to schools closing. IPAC measures and level of schooling included in the study were not described.	Days to school closing was associated with cumulative incidence on days 35 and 42, with an adjusted rate ratio of 1.59 (95% CI: 1.03%–2.44%, *p*=0.04) at 35 days, and adjusted rate ratio of 1.64 (95% CI: 1.07%–2.52%, *p*=0.04) at 42 days. Delays in closing schools was positively associated with cumulative incidence at the state level.
Liu (2020) (22) Ecological study US Feb–Apr 2020	This study estimated the impact of nine different NPIs on reduction of the effective R_t by using the daily number of reported new cases and inferred infections in 50 states. IPAC measures and level of schooling included in the study were not described.	Closing schools was found to moderately reduce R_t by about 10% (95% CI: 7%–14%). This reduction was smaller than six other NPIs assessed (stay-at-home order, face masks, gathering ban, non-essential business closure, declaration of state of emergency and interstate travel restriction).
Yehya (2020) (35) Ecological study US Jan–Apr 2020	In this study, a state-level analysis was conducted to determine association between later implemented NPIs with higher mortality rates. Using a multivariable negative binomial regression, the association was tested between timing of emergency declarations and school closures with 28-day mortality. Day 1 for each state was set to when they recorded 10 or more deaths. IPAC measures and level of schooling included in the study were not described.	Later school closure was associated with more deaths (adjusted mortality rate ratio 1.05; 95% CI: 1.01%–1.09%; *p*=0.008).

Appendix Table A2: Summary of ecological studies assessing the effectiveness of school closures or re-openings on reducing spread of COVID-19 in the community (n=19) (*continued*)

Study	Method	Key outcomes
Asia (n=2)		
Cowling (2020) (32) Ecological study Hong Kong Jan–Feb 2020	This study examined the effect of public health interventions on the incidence of COVID-19 and on the daily effective R_t. Laboratory-confirmed COVID-19 cases and the daily effective R_t were estimated to determine changes in transmissibility over time. School closures included kindergartens up to tertiary and post-tertiary institutions, and tutorial centres. IPAC measures were not described.	The estimated R_t was 1.28 (95% CI: 1.26%–1.30%) during the 2-week period before the start of the school closures and 0.72 (95% CI: 0.70%–0.74%) during the first two weeks of school closures, corresponding to a 44% (95% CI: 34%–53%) reduction in transmissibility. R_t calculated from hospitalization data was 1.10 (1.06–1.12) before the start of the school closures and reduced to 0.73 (0.68–0.77) after school closures, corresponding to a 33% (95% CI: 24%–43%) reduction in transmissibility.
Kentaro (2020) (23) Ecological study Japan Mar 2020	This study aimed to assess the effectiveness of primary and secondary school closures on COVID-19 incidence nine days after implementation. IPAC measures were not described. Using a Bayesian method, time-series analyses were conducted, and local linear trend models were developed for the number of newly reported cases of COVID-19.	The school closure intervention was not effective in decreasing the incidence of COVID-19. The newly reported COVID-19 cases continued to rise (α - 0.08, 95% CI: -0.36%–0.65%).
Europe (n=2)		
Wieland (2020) (24) Ecological study Germany Mar–Apr 2020	The aim of this study was to assess the effectiveness of different NPIs against the spread of COVID-19 over time. School closures included day-care closures as well. IPAC measures were not described. Using publicly available data on daily reported German cases, exponential growth models for infections and R_t were estimated and investigated with respect to change points in the time series.	No significant effect was found on COVID-19 infections that could be attributed to school and day-care closures.
Ehrhardt (2020) (25) Ecological study Germany Feb–Aug 2020	This study aimed to assess the transmission of SARS-CoV-2 among children in primary schools, secondary schools and childcare facilities in Baden-Württemberg, Germany after school re-openings in May 2020. IPAC measures included: reduced class size, disinfecting, hand hygiene and banning of sports and music in primary and secondary schools. An epidemic curve was used to show daily new cases after the schools reopened.	Child-to-child transmission in schools was low. The study estimated that one secondary case originates per 25 infectious school days (days that cases spent at school during infectious period). School re-openings were not associated with a change in transmission of SARS-CoV-2.

Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; IPAC, infection prevention and control; NPI, non-pharmaceutical intervention; RRR, ratios of rate ratios; rs, respective stringency index; R_t, effective reproduction number; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SE; standard error; US, United States