Do school closures reduce community transmission of COVID-19? A systematic review of observational studies

Preprint · January 2021

DOI: 10.1101/2021.01.02.21249146

10 authors, including:

Sebastian Walsh
University of Cambridge
16 PUBLICATIONS 87 CITATIONS
SEE PROFILE

Simon Russell
University College London
27 PUBLICATIONS 1,481 CITATIONS
SEE PROFILE

Vickie Braithwaite
University of Cambridge
29 PUBLICATIONS 377 CITATIONS
SEE PROFILE

Claire Waddington
University of Cambridge
79 PUBLICATIONS 1,184 CITATIONS
SEE PROFILE

Do school closures reduce community transmission of COVID-19? A systematic review of observational studies

Authors:
Dr Sebastian Walsh[1], Dr Avirup Chowdhury[2], Dr Simon Russell[3], Dr Vickie Braithwaite[2], Dr Joseph Ward[3], Dr Claire Waddington[4], Prof Carol Brayne[1], Prof Chris Bonell[5], Prof Russell Viner[3] and Dr Oliver Mytton[2]

Author Affiliations:
[1]Cambridge Public Health, University of Cambridge
[2]MRC Epidemiology Unit, University of Cambridge
[3]Population, Policy & Practice Dept, UCL GOS Institute of Child Health
[4]Department of Medicine, University of Cambridge
[5]Faculty of Public Health and Policy, London School of Hygiene & Tropical Medicine

Corresponding Author:
Dr Sebastian Walsh
Cambridge Public Health
Forvie Site
Cambridge Biomedical Campus
Cambridge
CB2 0SR
Sjw261@medschl.cam.ac.uk

Word Count:
Abstract: 250
Manuscript: 3,426

Abstract

Introduction

School closures are associated with significant negative consequences and may exacerbate inequalities. They were implemented worldwide to control SARS-CoV-2 in the first half of 2020, but their effectiveness remains uncertain. This review summarises the empirical evidence of their effect on SARS-CoV-2 community transmission.

Methods

The study protocol was registered on Prospero (ID:CRD42020213699). On 12 October 2020 we searched PubMed, Web of Science, Scopus, CINAHL, the WHO Global COVID-19 Research Database, ERIC, the British Education Index, and the Australian Education Index. We included empirical studies with quantitative estimates of the effect of school closures/reopenings on SARS-CoV-2 community transmission. We excluded prospective modelling studies and intra-school transmission studies. We performed a narrative synthesis due to data heterogeneity.

Results

We identified 3,318 articles, of which ten were included, with data from 146 countries. All studies assessed school closures, and one additionally examined re-openings. There was substantial heterogeneity between studies. Three studies, including the two at lowest risk of bias, reported no impact of school closures on SARS-CoV-2 transmission; whilst the other seven reported protective effects. Effect sizes ranged from no association to substantial and important reductions in community transmission.

Discussion

Studies were at risk of confounding and collinearity from other non-pharmacological interventions implemented close to school closures. Our results are consistent with school closures being ineffective to very effective. This variation may be attributable to differences in study design or real differences. With such varied evidence on effectiveness, and the harmful effects, policymakers should take a measured approach before implementing school closures.

Panel: 'Research in context'

Evidence before this study

A previous systematic review, published by some of us in April 2020, found good evidence that school closures are effective for the control of influenza, but limited evidence of effectiveness for coronavirus outbreaks. At the time there was no available empirial evidence from the COVID-19 pandemic.

Added value of this study

This study is the first systematic review of the empirical evidence from observational studies of the effect of school closures and reopenings on community transmission of SARS-CoV-2. We include 10 studies, covering 146 countries. There was significant heterogeneity between studies. Some studies reported large reductions in incidence and mortality associated with school closures, however, studies were at risk of confounding and collinearity, and studies at lower risk of bias reported no association.

Implications of all the available evidence

The evidence is consistent with either no effect, or a protective effect of school closures. With such varied evidence on effectiveness, and the harmful effects, policymakers should take a measured approach before implementing school closures.

Introduction

School closures have been a common strategy to control the spread of SARS-CoV-2 during the COVID-19 pandemic. By 2 April 2020, 172 nations had enacted full closures or partial 'dismissals', affecting nearly 1·5 billion children[2]. However, school closures have significant negative consequences on children's wellbeing and education, which will impact on life chances and long-term health[3,4]. Closures may exacerbate existing inequalities. Children in higher income families may have better opportunities for remote learning.

Moreover, whilst the role of non-pharmaceutical interventions (NPIs) collectively in limiting community spread is established, the specific contribution of school closures remains unclear. Observational studies suggest that school-aged children, particularly teenagers, play a role in transmission to peers and bringing infection into households[8], although the relative importance compared to adults remains unclear[9]. Younger children appearless susceptible to infection and may play a smaller role in community transmission, compared with older children and adults[10]. Whilst some modelling studies have suggested that school closures can reduce SARS-CoV-2 community transmission[5], others disagree[6,7].

A rapid systematic review published in April 2020 found only limited evidence of the effectiveness of school closures in controlling the spread of coronaviruses.[1] However, this study was undertaken very early in the pandemic and included no observational data on SARS-CoV-2. Several empirical studies on the effects of school closures on SARS-CoV-2 community transmission have been published since the April review, but there has been no systematic review of these studies. Here, we synthesise the empirical published and grey literature on the impact of closing or reopening schools on COVID-19 incidence, hospitalisation, and mortality.

Methods

The study protocol for this systematic review is registered on Prospero (ID:CRD42020213699).

Inclusion and Exclusion Criteria

We included any empirical study which reported a quantitative estimate of the effect of school closure or reopening on community transmission of SARS-CoV-2. We considered 'school' to include early years settings (e.g. nurseries or kindergartens), primary schools, and secondary school, but excluded further or higher education (e.g. universities). Community transmission was defined as any measure of community infection rate, hospital admission rate, or mortality attributed to COVID-19.

We included studies published in 2020 only. We included pre-prints, peer-reviewed and grey literature. We did not apply any restriction on language, but all searches were undertaken in English. We excluded prospective modelling studies and studies in which the assessed outcome was exclusively transmission within the school environment rather than wider community transmission.

Search strategy

We searched PubMed, Web of Science, Scopus, CINAHL, the WHO Global COVID-19 Research Database (including Medrxiv), ERIC, the British Education Index, and the Australian Education Index, searching title and abstracts for terms related to SARS-CoV-2 AND terms related to schools or NPIs. To search the grey literature, we searched Google. Full details of the search strategy are included in Appendix A. No restrictions on dates were placed and all searches were undertaken on 12 October 2020.

Data extraction and risk of bias assessment

Article titles and abstracts were imported into the Rayyan QCRI webtool[11]. Two reviewers independently screened titles and abstracts, retrieved full texts of potentially relevant articles, and assessed eligibility for inclusion (SW assessed all articles; AC, SR and VB each assessed one third).

Two reviewers independently extracted data and assessed risk of bias. Data extraction was performed using a pre-agreed extraction template which collected information on publication type (peer-reviewed or pre-print), country, study design, exposure type (school closure or re-opening), setting type (primary or secondary), study period, unit of observation, confounders adjusted for, other NPIs in place, analysis method, outcome measure, and findings. We used the Cochrane Risk of Bias In Non-randomised Studies of Interventions (ROBINS-I) tool[12] to evaluate bias.

Discrepancies were resolved by discussion in the first instance and by a third reviewer if necessary.

Data synthesis

Given the heterogeneous nature of the studies, prohibiting meta-analysis, a narrative synthesis was conducted.

Results

We identified 3,318 studies (Figure 1). After removing 372 duplicates, 2,946 unique records were screened for inclusion. We excluded 2,814 records at the title or abstract stage, leaving 132 records for full text review. Ten of these met the inclusion criteria.

Included studies are described in Table 1. All studies [13–22] reported the effect of school closures on community transmission of SARS-CoV-2, and one study[21] additionally examined school re-opening. All studies used data from national Government sources or international data repositories, and reported on the first half of 2020.

Six studies reported data from a single country or region: the USA[13,14,17,20] (n=4), Japan[15] (n=1), and Jerusalem, Israel[21] (n=1). The remaining four reported data from multiple countries, of which two[16,19] provided estimates for an overall worldwide effect of school closures, and two provided estimates for three individual countries each (one study[22] France, Italy, USA; the other[18] Argentina, Italy, South Korea). All studies were ecological, and used a state (USA), regional, or national unit of analysis.

Five studies[13,15,17,20,21] specified that both primary and secondary schools were included (children aged 5 or 6 to 18); the others did not specify school type. No study provided independent estimates of the effect of closing either primary or secondary schools only.

Six studies specifically sought to estimate an effect of school closures on SARS-CoV-2 transmission.[13–15,17,18,21] The remaining four studies primarily sought to estimate the effect of NPIs (but reported an independent estimate for school closures within their analysis) .[16,19,20,22]

Several analytic approaches were used, including: various types of regression models (n-7),[13,14,16–20,22] time series analysis with Bayesian inference (n=1),[15] comparison to a synthetic control group derived from data from comparable countries (n=1),[18] and presentation of an epidemic curve[21].

In most instances of school closures, other NPIs were introduced at or around the same time and potentially confounded the estimate. One study[17] dealt with this by selecting US states that closed schools first and left a gap before implementing other NPI measures. Whilst another study[18] took a similar approach, choosing countries (South Korea, Italy and Argentina) that shut schools early relative to national lockdown; these countries had significant other NPIs in place at the time of school closure. Four studies[13,14,22,23] used statistical adjustment to control for other interventions. Four studies[15,16,20,21] did not account for other NPIs. Some studies also adjusted for other potential confounders, such as population factors (e.g. proportion of population aged ≥65, population density and testing regimes).

Regarding outcomes, eight studies[13–17,19,21,22] reported effects on incidence, and four studies[13,17,18,20] used mortality data (one of which[17] additionally reported hospitalisation rates). The assumed lag period from school closure to changes in incidence rate varied between seven and 20 days, with longer time periods of 26 to 28 days generally assumed for mortality.

Risk of bias of the studies is summarised in Table 2: two studies were found to be at low risk of bias[14,22], two at moderate risk[13,17], five at serious risk[15,16,18–20] and one at critical risk[21].

Table 3 reports study findings. Seven studies[13,16–21] reported that closing schools was associated with a reduction in incidence or mortality rates, whilst three[14,15,22] found no association. There was significant heterogeneity in the reported effect size of closing schools, ranging from precise estimates of no effect, to approximately halving the incidence and mortality rates[13]. The two studies with the lowest risk of bias[14,22] reported no effect of school closures on transmission.

At a country level, four studies[13,14,17,20] exclusively reported data from the USA, and one further study[22] reported an independent effect size for the USA. The results from these studies are discordant, with two studies reporting null effects[14,22], and the other studies reporting large preventative effects.[13,17,20] Two studies reported effect estimates for Italy, one being preventative[18] and one[22] tending towards a non-significant preventative effect. Single estimates that were preventative were observed for the following countries: Argentina[18], Israel[21], and South Korea[18]; with single estimates of no association for France[22] and Japan[15].

Of the eight studies that reported an effect on incidence, five[13,16,17,19,21] were preventative and three[14,15,22] had no effect. Only one study[17] reported an effect on hospitalisation, which was preventative. All four of the studies[13,17,18,20] that reported an effect on mortality reported a preventative effect.

Narrative Synthesis

We identified three study designs: within-area before-after comparisons, pooled multiple-area before-after comparisons, and pooled multiple-area cross-sectional comparisons.

Within-area before-after comparisons

Five studies[15,17,18,21,22] compared community transmission of SARS-CoV-2 before and after school closure/re-opening for single geographical units. This approach controls for confounding from population sociodemographic factors.

Of these, two studies sought to adjust for other NPIs.
Hsiang et al.[22] (low risk of bias) used a reduced form of econometric regression to compare changes in incidence in six countries (China, France, Iran, Italy, USA and South Korea) before and after NPI implementation. Other key NPIs and testing regimes were adjusted for. Effect sizes for school closures were only reported for France, Italy and the USA; but (and without explanation) not for China, Iran or South Korea. The authors report a null effect of school closures on growth rate of SARS-CoV-2 incidence, with narrow confidence intervals for France and the USA, but a regression coefficient suggestive of a non-significant preventative effect in Italy (-0·11 (95% CI -0·25, 0·03)).
Neidhofer et al.[18] (serious risk of bias) used a difference in difference comparison to estimate reduction in deaths in the 18 days post-school closure in Argentina, Italy and South Korea; compared with synthetic controls derived from the weighted average of epidemic curves from countries that closed schools later. This method indirectly adjusted for some

confounders by selecting the most comparable countries with regards to both sociodemographic features and the number of SARS-CoV-2 deaths at the time of closure (Argentina 2, South Korea 22, Italy 80). The authors reported a 63%-90% reduction, 21%-35% reduction, and 72%-96% reduction in the daily average COVID-19 deaths in Argentina, Italy and South Korea respectively. The small number of cumulative deaths in Argentina and South Korea at the start of the study period made reliable extrapolation of mortality trends to inform the control units unlikely.

The other three studies did not analytically adjust for other NPIs.
Matzinger et al.[17] (moderate risk of bias) identified the three US states which introduced school closures first, and with a sufficient lag before implementing other measures to assess their specific impact. They plotted incidence rates on a $\log_2$ scale and identified points of inflexion in the period after school closure. This assumes exponential growth in the absence of interventions, which may not have occurred given changes to testing regimes. The doubling time of new cases in Georgia slowed from 2·1 to 3·4 days one week after closing schools. Similar results were observed in Mississippi (1·4 to 3·4 days) and Tennessee (2·0 to 4·2 days). The authors also noted inflexion points for hospitalisations and mortality, although numerical changes were not reported. Tennessee showed a slowing in hospitalisations after one week, and deaths another week later; whereas Mississippi shows a slowing of both at the same time (after one week) – the authors do not comment on this discrepancy. Georgia lacked early hospitalisation data to make such a comparison.
Iwata et al.[15] (serious risk of bias) used time series analysis with Bayesian Inference to estimate the effects of school closures on SARS-CoV-2 incidence in Japan, reporting a null effect. Whilst growth in cases was observed during the study period, the number of cases remained low (<100 cases per day). Publicly available data[24] shows implementation of mass gathering bans occurred with school closures, and foreign travel bans were already in place.
Stein-Zamir et al.[21] (critical risk of bias) reported an age-stratified epidemic curve of SARS-CoV-2 incidence in Jerusalem, with identification of the timing of school closures and re-openings. They show a large reduction in incidence starting one week after schools closed, with proportional reductions across all age groups; and a resurgence in case numbers around two weeks after schools were gradually re-opened, predominantly driven by younger age groups. There is no adjustment for other NPIs, though school closures were implemented alongside mass gathering bans and other social distancing rules; whilst school re-openings coincided with lifting hospitality and retail restrictions, and relaxing mass gathering bans[25]. Mass testing of a single secondary school was undertaken as part of an outbreak investigation, and the sharp increase in the number of new cases amongst young people is almost entirely accounted for by the cases identified by this.

Pooled multiple-area before-after comparisons.
Three studies[13,14,20] reported data on multiple geographical units, and then pooled the results into one unified estimate of effect using regression analysis.

One study had a low risk of bias and reported a null effect. Courtemanche et al.[14] used a fixed effects model (which accounts for inter-area sociodemographic differences) to estimate the effect of school closures on SARS-CoV-2 incidence in US counties. They adjusted for relevant NPIs and testing regime confounders, and reported a null effect of school closures on growth rate applying a lag of either 10 or 20 days.

Two studies had a higher risk of bias due to a lack of adjustment for confounding NPIs, and reported preventative effects.
Auger et al.[13] (moderate risk of bias) used interrupted time series analysis to calculate the rate of change in SARS-CoV-2 incidence and mortality in US states, and then used negative binomial regression to combine effect sizes into one pooled national estimate. Stepwise regression was used to build models, excluding covariates with P values >0·20, resulting in exclusion of several NPIs and testing regime data from their models. They estimated that school closures reduced incidence and mortality by c.60%.
Yehya et al.[20] (serious risk of bias) also used negative binomial regression to combine the observed effects in US states, with COVID-19 mortality as the outcome measure. Relevant sociodemographic differences between states were accounted for as confounders in the multivariable model. However, they did not adjust for the effect of other NPIs. They estimated that school closures reduced COVID-19-related deaths by 5% per day.

Pooled multiple-area cross-sectional comparisons
Two studies[16,19] considered countries from around the world in a cross-sectional design in which NPIs were considered as binary variables on a specific date: in place or not in place, and the cumulative incidence to that point was compared to the number of new cases of COVID-19 over a subsequent follow-up period; countries were then compared using regression analysis to elicit independent effect sizes for individual policies including school closures. This approach reduces bias from different testing regimes over time and between countries. However, the use of a single cut-off date for whether school closure was in place means that that the effects of long-standing and more recent school closures were pooled. Both studies reported preventative effects of school closures on SARS-CoV-2 incidence (Juni et al.[16]:23% relative reduction in the incidence rate, Wong et al.[19]: 50% relative reduction).

Juni et al.[16] (serious risk of bias) used an exposure cut-off date of 20 March 2020 with a ten-day lag period and seven-day follow-up period. The authors adjusted for a comprehensive set of sociodemographic and geographical confounders (see Table 3) but did not adjust for the effect of other NPIs because they were implemented around the same time as school closures. Wong et al.[19] (serious risk of bias) used a cut-off data of 31 March with a 14-day lag period and a 14-day follow-up period. The authors only adjusted for potential sociodemographic confounding from gross domestic product and population density. The authors did adjust for the presence of other NPIs using the Stringency Index, but this does not include relevant measures such as social distancing rules or mask wearing.

Discussion

We identified ten studies that provided a quantitative estimate of the impact of school closures on community transmission of SARS-CoV-2. The studies spanned a range of countries and were heterogenous in design. Findings ranged from no association to a 62% relative reduction in incidence and mortality rate[13]. The studies at lowest risk of bias reported no association[14,22] (figure 2), whilst those with a higher risk of bias generally reported preventative effects. An exception was a paper by Matzinger et al.[17] which focused on US states that implemented school closures first and without co-interventions, and reported a two-fold increase in the time for cases to double one week after school closures.

A major challenge with estimating the 'independent' effect of school closures is disentangling their effect from other NPIs occurring at the same time. Most studies tried to account for this, but it is unclear how effective these methods were. In direct correspondence one author reported that adjustment for other NPI was not possible due to clustering.[16] Even where adjustment occurred there is a risk of residual confounding, which likely overestimated preventative associations; and collinearity (highly-correlated independent variables meaning that is impossible to estimate specific effects for each) which could bias results towards or away from the null. Four studies did not specifically seek to estimate an effect size for school closures, instead studying school closures as an example of NPIs. These studies may not have specified the model in an optimal way to estimate effects of school closures. The divergent results for the USA, highlight these problems and may suggest that methodological differences are an important cause in the variation of the findings.

The strength of this study is that it draws on empirical data from actual school closures during the COVID-19 pandemic and includes data from 146 countries. By necessity, we include observational rather than randomised controlled studies, as understandably no jurisdictions have undertaken such trials. We were unable to meta-analyse due to study heterogeneity. We were unable to examine differences between primary and secondary schools as no studies distinguished between them, despite the different transmission patterns for younger and older children.

The studies are not able to distinguish between the direct and indirect effect of school closures. Indirect effects might include parents staying at home (reducing workplace contacts), and the signalling effect that closing schools sends to the general population to be cautious and reduce social contacts. Whilst some studies reported effects on mortality, it was not always clear whether the specified timeframe was appropriate. Interventions affecting children would be expected to have a longer lag than other interventions: to allow time for impacts on infections in older adults and ultimately mortality. Data are also lacking from low-income countries, where sociocultural factors may produce different effects of school closures on transmission to high income settings, leaving a substantial gap in the evidence base.

Our estimates describe the impact of school closures policies early in the year. School re-opening, with substantial infection prevention measures in place, may have a very different effect on community transmission. Where school re-openings have occurred but other NPIs have remained, less biased estimates of effect may be possible. Data from school holidays should also be considered for future high-quality natural experiment studies. In addition, none of the included studies used mobility or genomic sequencing of viral strains which may have allowed for a mechanistic understanding of how school closures effect community transmission patterns.

The variability in findings from our included studies are likely to reflect issues with study design. However, this may also suggest that there is no single effect of school closures on community transmission and that contextual factors may modify the impact of closures in different countries and over time. If the purpose of school closures is reduction in social contacts among children, the level of social mixing between children that occurs outside school once schools are closed is likely to be a key determinant of their effect at reducing community transmission . This will be influenced by other NPIs, and other key contextual factors including background prevalence of infection, age of children affected, as well as sociodemographic and cultural factors.

Different countries have adopted different approaches to controlling COVID-19. In the first wave of the pandemic school closures were common, and in some places one of the first major social distancing measures used. In contrast, the UK Government's strategy for managing the second wave has prioritised keeping educational institutions open. With such varied findings and quality of evidence on the effect of school closures on limiting community transmission of SARS-CoV-2, and given the harmful effects of school closures[3,4], policymakers and governments need to take a measured approach before implementing school closures in response to rising infection rates.Other evidence, such as the harms of school closures and transmission patterns in children should be considered alongside the evidence presented here when making decisions about school closures. Less damaging measures such as effective test, trace and isolate regimes in schools, as well as enhanced hygiene and social distancing measures should be considered as alternatives to school closures. This work also underscores the need for a robust and systematic approaches to the evaluation of all interventions deployed in a pandemic, not just those readily amenable to randomisation.

Acknowledgements

Author Contributions:

SW, CW, CBo, RV and OM designed the review protocol. SW, AC, SR and VB screened articles for inclusion, assessed risk of bias, and performed data extraction. SW and OM drafted the manuscript. All authors commented on the final manuscript.

Role of the funding source

There is no direct funding for this study. The funding bodies who support the researchers involved in this work had no role in study design, data collection, data analysis, data interpretation, or writing the 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.

Declaration of interests

The authors declare no conflicts of interest

References

1 Viner RM, Russell SJ, Croker H, *et al.* School closure and management practices during coronavirus outbreaks including COVID-19: a rapid systematic review. *Lancet Child Adolesc Heal* 2020; **4**: 397–404.

2 UNESCO. Global monitring of school closures caused by COVID-19. Educ. Disrupt. to Recover. 2020. https://en.unesco.org/covid19/educationresponse%0Ahttps://en.unesco.org/themes/education-emergencies/coronavirus-school-closures (accessed Dec 18, 2020).

3 UNESCO. Adverse consequences of school closures. 2020. https://en.unesco.org/covid19/educationresponse/consequences (accessed Dec 18, 2020).

4 Lee J. Features Mental health effects of school closures during COVID-19. *LANCET CHILD Adolesc Heal* 2020; **4**: 421.

5 Panovska-Griffiths J, Kerr CC, Stuart RM, *et al.* Determining the optimal strategy for reopening schools, the impact of test and trace interventions, and the risk of occurrence of a second COVID-19 epidemic wave in the UK: a modelling study. *Lancet Child Adolesc Heal* 2020; published online Aug. DOI:10.1016/S2352-4642(20)30250-9.

6 Bayham J, Fenichel EP. Impact of school closures for COVID-19 on the US health-care workforce and net mortality: a modelling study. *Lancet Public Heal* 2020; **5**: e271–8.

7 Davies NG, Kucharski AJ, Eggo RM, Gimma A, Edmunds WJ. Effects of non-pharmaceutical interventions on COVID-19 cases, deaths, and demand for hospital services in the UK: a modelling study. *Lancet Public Heal* 2020; **5**: e375–85.

8 ECDC. COVID-19 in children and the role of school settings in COVID-19 transmission. Stockholm, 2020 https://www.ecdc.europa.eu/en/publications-data/children-and-school-settings-covid-19-transmission#no-link.

9 Ismail SA, Saliba V, Lopez Bernal J, Ramsay ME, Ladhani SN. SARS-CoV-2 infection and transmission in educational settings: a prospective, cross-sectional analysis of infection clusters and outbreaks in England. *Lancet Infect Dis* 2020; published online Dec 18. DOI:10.1016/S1473-3099(20)30882-3.

10 Scientific Advisory Group for Emergencies. Update on children, schools and transmission - 4 November 2020. 2020.

11 Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan---a web and mobile app for systematic reviews. *Syst Rev* 2016; **5**: 210.

12 Sterne JAC, Hernán MA, Reeves BC, *et al.* ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. *BMJ* 2016; **355**. DOI:10.1136/bmj.i4919.

13 Auger KA, Shah SS, Richardson T, *et al.* Association Between Statewide School Closure and COVID-19 Incidence and Mortality in the US. *JAMA* 2020; **324**: 859–70.

14 Courtemanche C, Garuccio J, Le A, Pinkston J, Yelowitz A. Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate. *Health Aff (Millwood)* 2020; **39**: 1237–46.

15 Iwata K, Doi A, Miyakoshi C. Was school closure effective in mitigating coronavirus disease 2019 (COVID-19)? Time series analysis using Bayesian inference. *Int J Infect Dis IJID Off Publ Int Soc Infect Dis* 2020; **99**: 57–61.

16 Jüni P, Rothenbühler M, Bobos P, *et al.* Impact of climate and public health interventions on the COVID-19 pandemic: a prospective cohort study. *C Can Med Assoc J = J l'Association medicale Can* 2020; **192**: E566–73.

17 Matzinger P, Skinner J. Strong impact of closing schools, closing bars and wearing

masks during the Covid-19 pandemic: results from a simple and revealing analysis. medRxiv Prepr. Serv. Heal. Sci. 2020; published online Sept. DOI:10.1101/2020.09.26.20202457.

18 Neidhofer C, Neidhofer G. The effectiveness of school closures and other pre-lockdown COVID-19 mitigation strategies in Argentina, Italy, and South Korea. *ZEW Discuss Pap* 2020. https://pesquisa.bvsalud.org/portal/resource/en/mdl-20203403367.

19 Wong MC, Huang J, Teoh J, Wong SH. Evaluation on different non-pharmaceutical interventions during COVID-19 pandemic: An analysis of 139 countries. J. Infect. 2020; **81**: e70–1.

20 Yehya N, Venkataramani A, Harhay MO. Statewide Interventions and Covid-19 Mortality in the United States: An Observational Study. *Clin Infect Dis an Off Publ Infect Dis Soc Am* 2020; published online July. DOI:10.1093/cid/ciaa923.

21 Stein-Zamir C, Abramson N, Shoob H, *et al.* A large COVID-19 outbreak in a high school 10 days after schools' reopening, Israel, May 2020. *Eurosurveillance* 2020; **25**. DOI:10.2807/1560-7917.ES.2020.25.29.2001352.

22 Hsiang S, Allen D, Annan-Phan S, *et al.* The effect of large-scale anti-contagion policies on the COVID-19 pandemic. *Nature* 2020; **584**: 262–7.

23 Li Q, Guan X, Wu P, *et al.* Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus–Infected Pneumonia. *N Engl J Med* 2020; : NEJMoa2001316.

24 Wikipedia. COVID-19 Pandemic in Japan. 2020. https://en.wikipedia.org/wiki/COVID-19_pandemic_in_Japan (accessed Dec 22, 2020).

25 Steinman. COVID-19 and autism. *Med Hypotheses* 2020; **138**: 109797.

Table 1: Characteristics of included studies

Author, Year Title	Country	Study Design	Study Period	Setting Type	Unit of Exposure	Confounders/Co-Interventions Adjusted For	Other NPI Measures	Analysis Type
(i) Within-area before-after comparisons								
Hsiang, 2020 The effect of large-scale anti-contagion policies on the COVID-19 pandemic	Italy, France, USA	Within-area before-after comparison study	Study period: 25/02/20 - 06/04/20 Exposure date: Varied by country Lag period: No lag applied	Not specified	Provincial/Regional level (Italy and France), State level (USA)	Other NPIs (travel ban and quarantine, work from home order, no social gatherings, social distancing rules, business and religious closures, home isolation), test regimes	Variable	Reduced-form econometric (regression) analysis to estimate the effect of school closures on the continuous growth rate (log scale)
Iwata, 2020 Was school closure effective in mitigating coronavirus disease 2019 (COVID-19)? Time series analysis using Bayesian inference	Japan	Within-area before-after comparison study	Study period: 27/01/20 - 31/03/20 Exposure date: 29/02/20 Lag period: 9 days	Primary and secondary schools (age 6-18)	Country	None specified	None specified	Time series analysis using Bayesian inference to estimate effect of school closures on the incidence rate of COVID-19

Matzinger, 2020 Strong impact of closing schools, closing bars and wearing masks during the COVID-19 pandemic: results from a simple and revealing analysis	USA	Within-area before-after comparison study	Study period: 06/03/20 - 01/05/20 Exposure date: Georgia: 14/03/20 Tennessee: 14/03/20 Mississippi: 06/03/20 Lag period: Under investigation	Primary and secondary schools (aged 5-18)	US State	None specified	None specified	Calculated changes to the doubling time of new cases, hospitalisations and deaths by plotting log2 of cases, hospitalisations and deaths against time, and using segmented regression to analyse changes in the trends in response to NPI implementation.
Neidhofer, 2020 The Effectiveness of School Closures and Other Pre-Lockdown COVID-19 Mitigation Strategies in Argentina, Italy, and South Korea	Argentina, Italy, and South Korea	Within-area before-after comparison study	Study period: Not specified Exposure date: Italy 04/03/20 Argentina 16/03/20 South Korea not specified Lag Period: 15 days	Not specified	Country	Indirectly adjusted for in derivation of counterfactual, based on most comparable countries for: population size and density, median age, % aged ≥65, GDP per capita, hospital beds per 100,000 inhabitants, public health expenditures, average number of reported COVID-19 deaths before day zero, growth rate of reported COVID-19 cases with respect to the day before, and mobility patterns	All 3 countries: banning of public events, restriction of international flights, contact tracing, public information campaigns. Other interventions in place in each country, but	Difference in difference comparison to a synthetic control unit (derived from the weighted average of the epidemic curves from comparable countries that closed schools later), to estimate the % reduction in deaths in the 18 days post-school closure

						retrieved from Google Mobility Reports	unclear which	
Stein-Zamir, 2020 A large COVID-19 outbreak in a high school 10 days after schools' reopening, Israel, May 2020	Israel	Within-area before-after comparison study	Study period: 23/02/20 - 14/06/20 Schools closed: 13/03/20 Schools gradually reopened between: 03/05/20-18/05/20 Outbreak started: 26/05/20	All schools closed. Kindergartens, grades 1-3 and 11-12 reopened first, then all classes	Jerusalem, Israel	None specified	None specified	Presentation of an age-stratified epidemic curve showing confirmed cases of COVID-19 in Jerusalem, by date

(ii) Pooled multiple-area before-after comparisons

Auger, 2020 Association Between State-wide School Closure and COVID-19 Incidence and Mortality in the US	USA	Pooled multiple-area before-after comparison study	Study period: 09/03/20 - 07/05/20 Exposure date: 13/03/20 - 23/03/20 Lag for incidence: 16 days (IQR 10-21) Lag for mortality: 26 days (IQR 20-33)	Primary and secondary schools (aged 5-18)	US State	Included in both analyses Cumulative COVID-19 cases pre-school closure. % of population under 15, % of population over 65, % nursing home residents, social vulnerability index, and population density. Incidence only NPIs pre-school closure (restaurant closure, stay-at-home orders). NPIs post-school closure (stay-at-home orders). Testing rate pre- and post-school closure. Mortality only NPIs pre-school closure (restaurant closure, mass gathering ban, stay-at-home orders). NPIs post-school closure (restaurant closures, stay-at-home orders).	Variable	Negative binomial regression to estimate effect of school closures on the changes in incidence and mortality rates, as calculated by interrupted time series analysis.

Courtemanche, 2020 Strong Social Distancing Measures In The United States Reduced The COVID-19 Growth Rate	USA	Pooled multiple-area before-after comparison study	Study period: 01/03/20 - 27/04/20 Exposure date: Variable, generally mid-March Lag period: 10 and 20 days	Not specified	US counties, or county equivalents	Other NPIs (stay at home orders, hospitality closure, limiting gathering size), total daily tests done in that state	Variable	Fixed effects regression to estimate the effect of school closure on the growth rate of cases (% change)
Yehya, 2020 State-wide Interventions and Covid-19 Mortality in the United States: An Observational Study	USA	Pooled multiple-area before-after comparison study	Study period: 21/01/20 - 29/04/20 Exposure measure: Time (days) between 10th Covid-19 death and school closure Lag (school closure to mortality): 28 days	Primary and secondary schools (aged 5-18)	US state	Population size, population density, % aged <18, % aged ≥65, % black, % Hispanic, % in poverty, geographical region	Variable	Multivariable negative binomial regression to estimate mortality rate ratios associated with each day of delaying school closure

(iii)	Pooled multiple-area cross-sectional comparisons							
Juni, 2020 Impact of climate and public health interventions on the COVID-19 pandemic: a prospective cohort study	Worldwide (144 countries)	Pooled multiple-area cross-sectional comparison study	Study period: First available data to 28/03/20 Exposure cut-off date: 11/03/20 Lag period: 10 days	Not specified	Country	Country-specific factors (GDP per capita, health expenditure as % of GDP, life expectancy, % aged ≥65, Infectious Disease Vulnerability Index, urban population density), geography factors (flight passengers per capita, closest distance to a geopolitical area with an already established epidemic, geographical region) climatic factors (temperature, humidity)	Variable	Weighted random-effects regression analysis to estimate the effect of school closures on the changes to the incidence rate (measured as the ratio of rate ratios, dividing cumulative cases up to 28/03/20, by cumulative cases until 21/03/20, for each area)
Wong, 2020 Evaluation on different non-pharmaceutical interventions during COVID-19 pandemic: An analysis of 139 countries	Worldwide (139 countries)	Pooled multiple-area cross-sectional comparison study	Study period: 31/03/20 - 30/04/20 Exposure cut-off date: 31/03/20 Lag period: 14 days	Not specified	Country	Stringency index (workplace closure, public event cancelation, restrictions on gathering size, public transport closure, stay at home orders, restrictions on internal movement and international travel, public information campaigns, GDP, population density)	Variable	Multivariable linear regression to estimate the effect of school closures on the rate of increase in cumulative incidence of COVID-19

NPI = Non-pharmaceutical intervention

Table 2: Findings from the risk of bias assessment using the ROBINS-I tool

Author	**Confounding or Co-Intervention Bias**	**Selection Bias**	**Misclassification Bias**	**Deviation Bias**	**Missing Data Bias**	**Outcome Measurement Bias**	**Outcome Reporting Bias**	**Overall Judgement**	**Likely Direction**
Courtemanche	Low	Low	Low	Low	Low	Low	Low	**Low**	**-**
Hsiang	Low	Low	Low	Low	Low	Low	Low	**Low**	**-**
Auger	Moderate	Low	Low	Low	Low	Low	Low	**Moderate**	**Favours Experimental**
Matzinger	Low	Low	Low	Low	Low	Moderate	Low	**Moderate**	**Unpredictable**
Iwata	Serious	Low	Low	Low	Low	Moderate	Low	**Serious**	**Unpredictable**
Juni	Serious	Low	Low	Low	Low	Low	Low	**Serious**	**Favours Experimental**
Neidhofer	Serious	Serious	Low	Low	Low	Low	Moderate	**Serious**	**Favours Experimental**
Wong	Serious	Low	Low	Low	Low	Low	Low	**Serious**	**Unpredictable**
Yehya	Serious	Low	Low	Low	Low	Moderate	Low	**Serious**	**Favours Experimental**
Stein-Zamir	Critical	Low	Low	Low	Low	Serious	Low	**Critical**	**Unpredictable**

Scale applied: low, moderate, serious or critical.
“Favours experimental” indicates that the bias likely resulted in an exaggeration of the reduction in community transmission associated with school closures

Table 3: Findings from included studies, stratified by outcome measure and risk of bias

Author, Year	Outcome Measure	Findings	Other Comments
<u>Incidence</u>			
Low Risk of Bias			
Hsiang, 2020	Regression coefficient estimating effect of school closures on the continuous growth rate (log scale)	**No effect:** School closure not statistically associated with the growth rate of confirmed cases. Adjusted models: Italy: -0·11 (95% CI -0·25, 0·03) France: -0·01 (95% CI -0·09, 0·07) USA: 0·03 (95% CI -0·03, 0·09)	Sensitivity analysis applying a lag to NPI measures on data from China did not significantly alter the findings.
Courtemanche, 2020	Regression coefficient estimating effect of school closures on the growth rate of cases (% change)	**No effect:** School closure not statistically associated with the growth rate of confirmed cases. Adjusted models: Applying a 10-day lag: 1·71% (95% CI -0·38%, 3·79%) Applying a 20-day lag: 0·17% (95% CI -1·60%, 1·94%)	
Moderate Risk of Bias			
Auger, 2020	Regression coefficient estimating effect of school closures on changes to weekly incidence rates	**Preventative effect:** School closures were associated with decreases in the rate of growth of COVID-19 incidence. Adjusted model: 62% (95% CI: 49% - 71%) relative reduction in COVID-19 incidence.	Sensitivity analysis of shorter and longer lag periods did not significantly alter the findings. Early school closure associated with greater relative reduction in COVID-19 incidence than late closure.
Matzinger, 2020	Changes to the doubling time of the epidemic in each state, following school closures	**Preventative effect:** School closures were associated with reductions in the doubling time of new COVID-19 cases.	

		Georgia: 7 days after school closures the doubling time slowed from 2·1 days to 3·4 days Tennessee: 8 days after school closures the doubling time slowed from 2 days to 4·2 days Mississippi: 10-14 days after school closures the doubling time slowed from 1·4 days to 3·5 days	
Severe Risk of Bias			
Iwata, 2020	Time series analysis coefficient estimating effect of school closures on the change in daily incidence rate	**No effect:** School closure not statistically associated with the incidence rate of new cases. Expected daily decrease in daily new reported cases: 0·08 (95% CI -0·36, 0·65)	Sensitivity analysis for different lag times did not change the general finding of null effect.
Juni, 2020	Regression coefficient estimating effect of school closures on changes to the incidence rate	**Preventative effect:** School closures were statistically significantly associated with a relative reduction in the incidence rate of COVID-19. Adjusted model: 0·77 (95% CI 0·63 – 0·93) P=0·009	Sensitivity analyses of separating out high income countries, and areas with higher prevalence did not significantly affect the results.
Wong, 2020	Regression coefficient estimating effect of school closures on the rate of increase in cumulative incidence	**Preventative effect:** School closures were associated with a smaller rate of increase in cumulative incidence of COVID-19. Adjusted model: -0·53 (95% CI -1·00, -0·06) P=0·027	

Critical Risk of Bias			
Stein-Zamir, 2020	Presentation of an age-stratified epidemic curve showing confirmed cases of COVID-19 in Jerusalem, by date, and comparing to dates of school closure/re-opening	**Preventative effect:** School closures were associated with a reduction in new cases of COVID-19. School reopenings were associated with an increase in new cases of COVID-19. Difficult to elicit exact effect sizes from the epidemic curve, but approximately one week after schools were closed, the number of new cases started to decline. Approximately two weeks after schools started to reopen, the number of new cases started to increase	Reductions in cases after school closures appeared to be proportionately distributed throughout the age groups. Increases in cases after school reopening was more pronounced in younger age groups (10-19), but were also seen across all ages to a lesser extent
Mortality			
Moderate Risk of Bias			
Auger, 2020	Regression coefficient estimating effect of school closures on changes to weekly mortality rates	**Preventative effect:** School closures were associated with decreases in the rate of growth of COVID-19 mortality. Adjusted model: 58% (95% CI 46% - 67%) relative reduction in mortality per week.	Sensitivity analysis of shorter and longer lag periods did not significantly alter the findings. Early school closure associated with greater relative reduction in COVID-19 mortality than late closure

Matzinger, 2020	Changes to the doubling time of the number of hospitalisations and deaths in each state, following school closures	**Preventative effect:** School closures were associated with reductions in the doubling time of new COVID-19 hospitalisations and deaths. Patterns appeared to be similar to changes in incidence, lagging behind by 7-14 days, though these data were not always reported and more difficult to interpret.	
Serious Risk of Bias			
Neidhofer, 2020	% Reduction in deaths in the 18 days post-school closure, compared to synthetic control unit	**Preventative effect:** School closures were associated with reductions in COVID-19 mortality. Results by country: Argentina: 63% - 90% reduction, Italy: 21% - 35% reduction, South Korea: 72% - 96% reduction in daily average COVID-19 deaths	Sensitivity analysis using only excess mortality in Italy reached similar conclusion.
Yehya, 2020	Regression coefficient estimating increase in mortality at 28 days associated with each day school closures were delayed	**Preventative effect:** Every day a state delayed implementing school closure increased mortality risk by 5% (MMR 1·05 95% 1·01, 1·09)	Sensitivity analyses for starting exposure from 1st Covid death, or for excluding New York/New Jersey from analysis, did not significantly change the findings.

"Preventative effect" = school closures independently associated with reduction in community transmission. "No effect" = No association

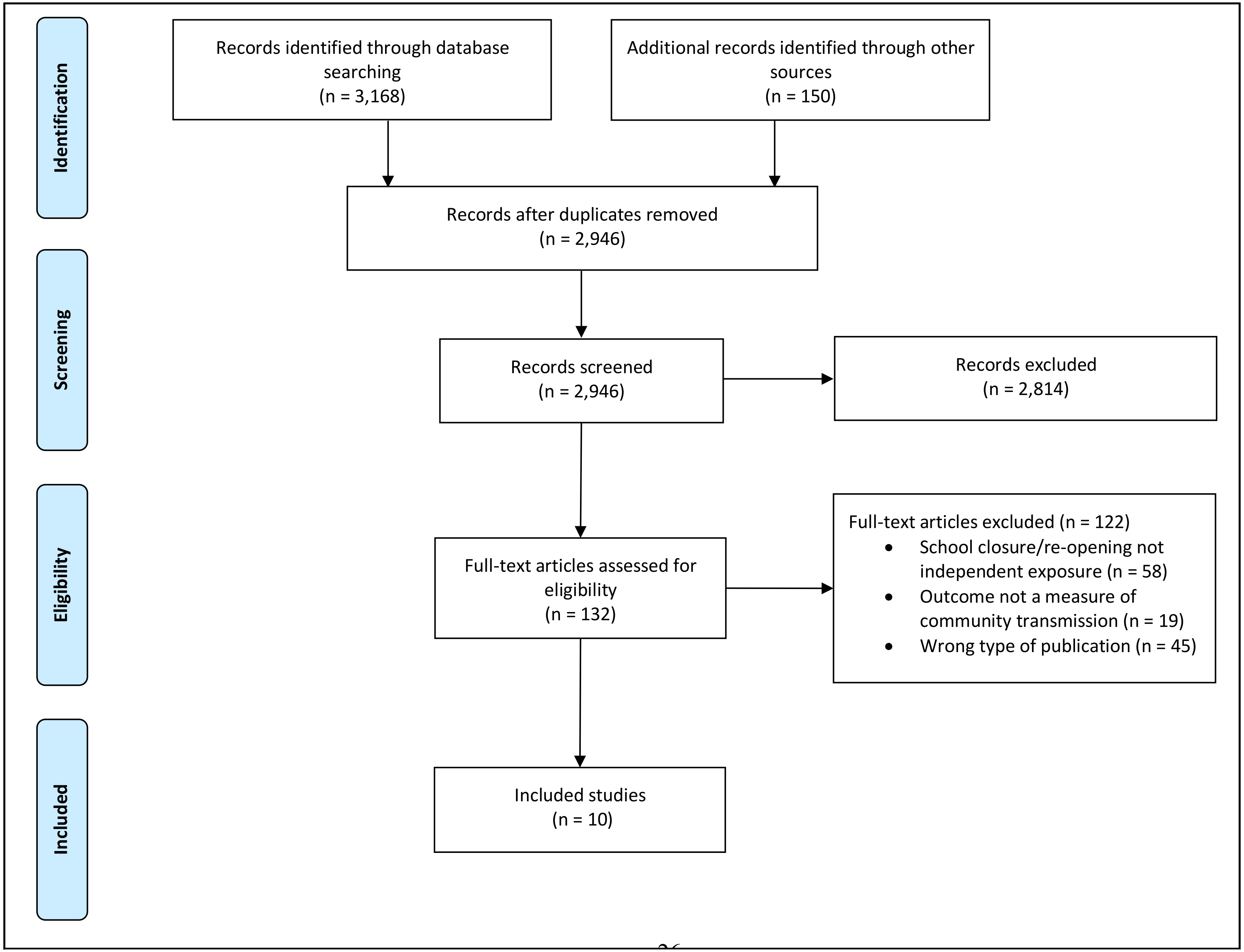

Figure 1: Flow diagram of study selection process

Author, Year	Finding	Overall Judgement	Likely Direction
Courtemanche, 2020	**No effect**	**Low**	-
Hsiang, 2020	**No effect**	**Low**	-
Auger, 2020	Preventative effect	Moderate	Favours Experimental
Matzinger, 2020	Preventative effect	Moderate	Unpredictable
Iwata, 2020	No effect	Serious	Unpredictable
Juni, 2020	Preventative effect	Serious	Favours Experimental
Neidhofer, 2020	Preventative effect	Serious	Favours Experimental
Wong, 2020	Preventative effect	Serious	Unpredictable
Yehya, 2020	Preventative effect	Serious	Favours Experimental
Stein-Zamir, 2020	Preventative effect	Critical	Unpredictable

Figure 2: Study results, stratified by risk of bias

Appendix A – Search Strategy
Search date: 12/10/20

PubMed
Search Title/Abstract:
(coronavirus[mh] OR Coronavirus Infections[mh] OR coronavirus*[tw] OR "COVID-19"[tw] or "2019-nCoV"[tw] or "SARS-CoV-2"[tw]) AND (Schools[mh:noexp] OR schools, nursery[mh] OR "Child Day Care Centers"[mh] OR "Nurseries, Infant"[mh] OR school*[tiab] OR preschool*[tiab] OR "pre-school*"[tiab] OR nurser*[tiab] OR kindergarten*[tiab] OR "day care"[tiab] OR daycare[tiab] OR "education setting*"[tiab] OR "educational setting*"[tiab] OR NPI*[tiab] OR "non-pharmaceutical intervention*"[tiab])

Web of Science
TS=(coronavirus* OR "COVID-19" OR "2019-nCoV" OR "SARS-CoV-2")
AND
TS=(school* OR nurser* OR preschool* OR "pre-school*" OR kindergarten* OR "day care" OR daycare OR "education setting*" OR "educational setting*" OR NPI* OR "non-pharmaceutical intervention*")

Scopus
TITLE-ABS-KEY ((coronavirus* OR "COVID-19" OR "2019-nCoV" OR "SARS-CoV-2") AND (school* OR nurser* OR preschool* OR "pre-school*" OR kindergarten* OR "day care" OR "daycare" OR "education setting*" OR "educational setting*" OR NPI* OR "non-pharmaceutical intervention*")) AND (LIMIT-TO (PUBYEAR , 2020))

CINAHL (via HDAS)
((coronavirus* OR "COVID-19" OR "2019-nCoV" OR "SARS-CoV-2") AND (school* OR nurser* OR preschool* OR "pre-school*" OR kindergarten* OR "day care" OR "daycare" OR "education setting*" OR "educational setting*" OR NPI* OR "non-pharmaceutical intervention*")).ti,ab [DT 2020-2020]

WHO Global COVID-19 Research Database
(tw:(school*)) OR (tw:(nurser*)) OR (tw:("pre-school*")) OR (tw:(preschool*) OR (tw:(kindergarten*)) OR tw:("day care") OR tw:("daycare") OR tw:("education setting*") OR tw:("educational setting*") OR tw:(NPI*) OR tw:("non-pharmaceutical intervention*"))
Including: WHO COVID Database, MedRxiv. Title, abstract, subject. 2020.

ERIC
Coronavirus OR "COVID-19" or "2019-nCoV" or "SARS-CoV-2"

British Education Index
Coronavirus OR "COVID-19" or "2019-nCoV" or "SARS-CoV-2"

Australian Education Index
Coronavirus OR "COVID-19" or "2019-nCoV" or "SARS-CoV-2"

Grey Literature Search, Google
First 100 hits on google search, limiting to PDF files, up to 'last year'.
Search: "COVID-19" OR "coronavirus" OR "school" OR "education"