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Title:
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Date:
2025-02-01

Citation:
Ong, D. S., Harris, M., Hart, J. D. & Russell, F. M. (2025). Lack of correlation between school reopening and trends in adult COVID-19 hospitalisations and death rates during the Delta and early Omicron periods: An ecological analysis of five countries. Journal of Infection, 90 (2), https://doi.org/10.1016/j.jinf.2024.106390.

Persistent Link:
https://hdl.handle.net/11343/361750

Journal of Infection 90 (2025) 106390

Contents lists available at ScienceDirect

Journal of Infection

journal homepage: www.elsevier.com/locate/jinf

Viruses and Viral Diseases

Lack of correlation between school reopening and trends in adult COVID-19 hospitalisations and death rates during the Delta and early Omicron periods: An ecological analysis of five countries

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ARTICLE INFO

Article history:
Accepted 22 December 2024
Available online 6 January 2025

Keywords:
COVID-19
SARS-CoV-2
School
Community transmission

SUMMARY

Objectives: In this ecological study, we describe SARS-CoV-2 case incidence and COVID-19 hospitalisation and death rates for school-aged and adult populations during the Delta and early Omicron periods, before and after schools reopened in five countries.

Methods: Data were extracted from government websites. Cases and COVID-19 hospitalisation and death incidence rates were calculated during the Delta and early Omicron periods in Australia, Canada, Denmark, Finland and the United Kingdom, for two weeks preceding and six weeks after schools reopened. We summarised stringency of public health measures (GRI), COVID-19 vaccination rates by age and SARS-CoV-2 testing rates.

Results: During Delta, cases increased in 2/7 sites after schools reopened, hospitalisations increased in 1/5 sites, while deaths decreased in one and increased then decreased in another. During Omicron, cases increased in 2/8 sites, hospitalisations increased in 1/6 sites and deaths increased in 1/4 sites. The hospitalisation and death rate trends that commenced before schools reopened continued on the same trajectory after schools reopened. Vaccination rates in ≥70-year-olds were 75–100% during Delta and 95–100% during Omicron. Wide variations in testing rates may explain differences in case incidence. GRI were higher and more variable during Delta than during Omicron.

Conclusions: Reopening schools did not change the existing trajectory of COVID-19 rates.

Introduction

One of the most controversial public health and safety measures adopted during the coronavirus disease 2019 (COVID-19) pandemic were school closures. An estimated 1.6 billion students were moved to remote learning during the peak of school closures with widespread impacts on the provision of services,[1,2] resulting in negative effects on the cognitive, social, emotional and physical development of children and adolescents.[3] Despite many countries adopting this strategy in the early phases of the pandemic, the impact of school closures on COVID-19 epidemiology remains unclear.

Some severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission and disease models found that opening schools without appropriate capacity for mitigation measures would introduce another wave of SARS-CoV-2 infections.[4] In contrast, observational studies during the first two years of the pandemic found minimal or no evidence that onsite learning in school settings increased community transmission.[5–12] In 2020, a comparison between Finland and Sweden, two similar countries that applied different school-based measures during the pandemic, found that school closures had no measurable direct impact on the number of laboratory-confirmed cases in school-aged children in either country.[13] A retrospective study in Victoria, Australia, in 2020 found that schools mirror community transmission during periods of low community transmission.[10] Other studies also found that when schools were open for onsite learning with appropriate infection prevention and containment measures, within-school transmission mirrored that of community transmission.[14,15] Additionally, household transmission studies found that living with a child was either protective

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https://doi.org/10.1016/j.jinf.2024.106390

or had no to minimal increased risk of infection for adults in the household.[16–18] However, most of these household and school studies were undertaken before the emergence of the Delta and Omicron subvariants, which are more transmissible variants of concern than prior strains.

In this ecological study, we describe the epidemiology of SARS-CoV-2 in the context of returning to onsite schooling after a period of school holidays or school closures. Specifically, we describe age-stratified SARS-CoV-2 case incidence, COVID-19 hospitalisation rates and COVID-19 death rates in Australia, Canada, Denmark, Finland and the United Kingdom (UK) during the Delta and the early Omicron periods when schools were reopening. Additionally, we undertook a rapid literature review to summarise SARS-CoV-2 epidemiology following school reopening.

Methods

Study design

This ecological study describes SARS-CoV-2 epidemiology in the context of return to onsite schooling in Australia, Canada, Denmark, Finland and the UK (England and Scotland). These countries were chosen as their SARS-CoV-2 testing was free of charge with widespread availability, age-stratified surveillance data for the outcomes of interest were publicly available, and data were reported in English.

Outcomes

We included SARS-CoV-2 cases, COVID-19 hospitalisation and COVID-19 death data from government surveillance websites (Supplementary S1). For Australia, we included state and territory-specific data from the Australian Capital Territory (ACT), New South Wales (NSW), Queensland, Tasmania, and Victoria as they were reported separately, and the epidemic varied by jurisdiction. Only Victoria and NSW had Delta outbreaks, while the other jurisdictions had no cases due to zero-COVID policies. For the UK, we included country-specific data from England and Scotland.

Timeframe

Observation periods during the Delta and early Omicron variants included the two weeks prior to reopening (holiday or school closure) and the six weeks following (post-holiday or post-school closure) the reopening of schools for onsite learning in each jurisdiction, subject to data availability (Table 1). This would allow for any impact of school reopening to be seen in COVID-19 hospitalisations and death epidemiology. For each variant, we focused on the first school term where schools fully resumed onsite schooling. Australian school dates (i.e. school holiday, COVID-19 closure, partial closure or fully onsite) were sourced from their respective government websites (Supplementary S1). School dates of other countries were sourced from the COVID-19 Education Response dashboard.[19]

Covariates

Transmission of SARS-CoV-2 is affected by other public health and social measures (PHSM). We utilised the COVID-19 Government Response Tracker as an indicator of the strictness of PHSM at any specific time during the study period (Supplementary S2), noting that this provides the highest level of stringency despite there being variation at sub-national level.[20] COVID-19 vaccination recommendations and coverage rates were obtained from their respective government websites (Supplementary S1). COVID-19 testing rates were obtained from Our World in Data.[21]

Data analysis

Data analysis was performed on Stata BE 18.0. We calculated rates of SARS-CoV-2 cases, COVID-19 hospitalisations and COVID-19 deaths in each country.

We divided the population into three age groups, namely primary school-aged children (5–11 years), secondary school-aged children (12–17 years) and non-school-aged people (all other age groups). Age-stratified SARS-CoV-2 case incidence, hospitalisation rates and death rates were calculated by dividing the total number of cases, hospitalisations or deaths on a particular day or week by the total population size, for each age group. Population data were obtained from their respective government websites (Supplementary S1). Moving seven-day averages were calculated where daily counts were provided, while seven-day averages were calculated where weekly counts were provided. In instances where the reported case counts did not align with our predefined age categories, we standardised the counts by dividing them by the number of age groups within the provided category. Subsequently, case counts were recalculated based on our predefined age categories. Similarly, when data were reported as rates instead of counts and did not correspond to our age categories, we adjusted by multiplying these rates by the age-specific population size to estimate the number of cases in each age category. This estimated number of cases was used to calculate the rates for our predefined age categories. Rates were described as SARS-CoV-2 cases, COVID-19 hospitalisations or COVID-19 deaths per week per 100,000 individuals for each age group. A narrative synthesis was undertaken to describe trends for each site and across sites, where possible.

Search strategy for the rapid literature review summarising SARS-CoV-2 epidemiology following school reopening

We searched PubMed on 11 December 2024 for observational studies and systematic reviews with the search terms: "school reopening" AND ("COVID-19" OR "SARS-CoV-2") AND ("community rates" OR "community incidence" OR "hospitalization" OR "death" OR "excess mortality"). Observational studies describing the epidemiology of SARS-CoV-2 community case incidence, COVID-19 hospitalisations, COVID-19 deaths and/or excess mortality in non-school-aged people following reopening were included after title, abstract and full-text screening by one reviewer (DSO). Modelling studies were excluded. We also searched the references from relevant systematic reviews and included any additional eligible studies that were not found in the initial literature search.

Results

The availability of SARS-CoV-2 case, COVID-19 hospitalisation and COVID-19 death data varied between countries and jurisdictions (Table 1). As expected, there was typically a two- to four-week lag between cases and hospitalisations and deaths.

SARS-CoV-2 case definitions, testing requirements and testing rates varied by site and observation period (Table 2). Age-stratified testing data were not available (Supplementary S3). All countries and jurisdictions implemented two-dose COVID-19 vaccination recommendations for all adults and children aged 12–17 years in 2021. Two-dose recommendations for children aged 5–11 years were implemented in late 2021 to early 2022 (Table 2).

Delta period

Detailed trends for each country and jurisdiction during the Delta observation period are shown in Fig. 1, Table 3 and described in Supplementary S4. Following school reopening, case incidence decreased in three sites (NSW, Victoria and Scotland) and increased

Table 1
Observation periods for each COVID-19 outcome, by country and jurisdiction.

Country		Outcome	Delta observation period	Omicron observation period
Australia	ACT	Cases	N/A	10/04/2022 – 29/05/2022[a]
		Hospitalisations	N/A	10/04/2022 – 29/05/2022[a]
		Deaths	N/A	N/A
	NSW	Cases	18/09/2021 – 15/11/2021[b]	14/01/2022 – 10/03/2022[b]
		Hospitalisations	18/09/2021 – 13/11/2021[a]	20/02/2022 – 12/03/2022[a,c]
		Deaths	18/09/2021 – 13/11/2021[a]	15/01/2022 – 12/03/2022[a]
	QLD	Cases	N/A	28/01/2022 – 24/03/2022[b]
		Hospitalisations	N/A	N/A
		Deaths	N/A	N/A
	TAS	Cases	N/A	16/04/2022 – 28/05/2022[a]
		Hospitalisations	N/A	16/04/2022 – 28/05/2022[a]
		Deaths	N/A	16/04/2022 – 28/05/2022[a]
	VIC	Cases	21/09/2021 – 15/11/2021[b]	N/A
		Hospitalisations	N/A	N/A
		Deaths	N/A	N/A
Canada		Cases	19/08/2021 – 13/10/2021[b]	27/12/2021 – 20/02/2022[b]
		Hospitalisations	N/A	N/A
		Deaths	N/A	N/A
Denmark		Cases	26/07/2021 – 13/09/2021[a]	20/12/2021 – 07/02/2022[a]
		Hospitalisations	26/07/2021 – 13/09/2021[a]	20/12/2021 – 07/02/2022[a]
		Deaths	N/A	20/12/2021 – 07/02/2022[a]
Finland		Cases	26/07/2021 – 13/09/2021[a]	27/12/2021 – 14/02/2022[a]
		Hospitalisations	26/07/2021 – 13/09/2021[a]	27/12/2021 – 14/02/2022[a]
		Deaths	N/A	N/A
United Kingdom	England	Cases	16/08/2021 – 04/10/2021[a]	20/12/2021 – 07/02/2022[a]
		Hospitalisations	16/08/2021 – 04/10/2021[a]	20/12/2021 – 07/02/2022[a]
		Deaths	N/A	N/A
	Scotland	Cases	18/08/2021 – 12/10/2021[b]	18/12/2021 – 11/02/2022[b]
		Hospitalisations	22/08/2021 – 10/10/2021[a]	19/12/2021 – 06/02/2022[a]
		Deaths	18/08/2021 – 12/10/2021[b]	18/12/2021 – 11/02/2022[b]

ACT: Australian Capital Territory; NSW: New South Wales; QLD: Queensland; TAS: Tasmania; VIC: Victoria; N/A: Data not available.
[a] Covers the week starting with the specified dates due to use of weekly data.
[b] Plotted as moving seven-day averages due to availability of daily data, rather than weekly data as for other countries and outcomes.
[c] Only three weeks of data were available.

then decreased in two sites (Canada and Finland). In Denmark, case incidence increased then fluctuated in primary school-aged children, decreased in secondary school-aged children and remained stable in non-school aged people.

Case rates were generally higher for school-aged children than non-school-aged people. Testing rates ranged from 1.66 to 16.01 tests per 1000 people, with the lowest rates in Canada and Finland and the highest rates in England and Scotland. Case incidence ranged from approximately 5 to 400, 5 to 450 and 3 to 200 cases per 100,000 people in primary school-aged children, secondary school-aged children and non-school-aged people, respectively. School based testing was available in NSW, Canada and England.

For the five sites with hospitalisation data, following school reopening, hospitalisations in NSW, England and Scotland declined overall but remained relatively stable overall in Denmark and Finland. For the two jurisdictions with death data, deaths decreased in NSW but initially increased before declining in Scotland. Hospitalisation rates varied by up to 12 times in non-school age population between sites. Denmark and Finland were similar at 1.5 to 2 per 100,000 (Fig. 1). NSW ranged from < 5 to 15 per 100,000. England was 6 to 8 per 100,000 and Scotland 12 to 18 per 100,000.

Death rates in the non-school-aged population were similar in the two sites with data (Fig. 1). In NSW, death rates were 0.3 to 1 per 100,000, and in Scotland were 0.4 to 1 per 100,000.

COVID-19 vaccination coverage rates varied between countries and jurisdictions. Coverage was high in the ≥70-year age group (75–100%) and highest in Scotland (100%). In the 16–17-year age group, coverage was also highest in Scotland (16%). In the 12–15-year age group, vaccination coverage was highest in Victoria (79%). Finland was the first country to recommend a two-dose schedule for the 16–17-year age group (early 2021) and Canada for the 12–17-year age group (May 2021). During the Delta period, all countries and jurisdictions had not recommended vaccination for the 5–11-year age group.

For 4/7 sites, the GRI was 60 to 80. The GRI was lowest in Finland, England and Scotland at 40 to 50. The GRI was higher during Delta and varied more between countries than during the early Omicron period.

Omicron period

Detailed trends for each country and jurisdiction for the Omicron observation period are shown in Fig. 2, Table 3 and described in Supplementary S4. Following school reopening, case incidence decreased in three jurisdictions (Canada, England and Scotland), decreased then increased in one jurisdiction (NSW), was stable in one jurisdiction (Tasmania), increased then decreased in two jurisdictions (ACT and Finland) and increased in two jurisdictions (Queensland and Denmark).

Case rates were generally higher for school-aged children than non-school-aged people in NSW, Queensland, Finland and Scotland, while the opposite was observed in Tasmania, Canada, Denmark and England. Compared to non-school-aged people in the ACT, secondary school-aged children generally had higher and primary school-aged children had lower case rates. Testing rates ranged from 1.66 to 32.89 tests per 1000 people, with the lowest rates in Canada and the highest rates in Denmark. School-based testing was available in the ACT, Queensland, Finland and Scotland.

For the six sites with hospitalisation data, following school reopening, hospitalisations decreased in two countries (England and Scotland), was stable in two countries (Denmark and Finland), initially increased then decreased in one jurisdiction (ACT) and fluctuated in one jurisdiction (Tasmania). For the four sites with death data, deaths decreased in one jurisdiction (NSW), increased then

Table 2
SARS-CoV-2 case definition, testing requirements, and COVID-19 vaccination recommendations and coverage in children aged 5–17 years during the Delta and Omicron observation periods, by country and jurisdiction.

Country		Delta observation period					Omicron observation period				
		Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]	Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]
Australia	ACT	N/A	N/A	N/A	N/A	N/A	April – May 2022	Positive PCR or RAT	Test if symptomatic, RAT available for free to students as required.	5–11 years: Two doses from January 2022 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	April 2022 5–11 years: 65% 12–15 years: > 99% May 2022 5–11 years: 68% 12–15 years: > 99%
	NSW	September – November 2021	Positive PCR	PCR testing only – advised to test if any symptoms or contact with a known case. RAT only used for workplace and school-based screening.	5–11 years: No recommendation 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	September 2021 5–11 years: N/A 12–15 years: 1% October 2021 5–11 years: N/A 12–15 years: 62% November 2021 5–11 years: N/A 12–15 years: 77%	January – March 2022	Positive PCR or RAT	Test if any symptoms with PCR and RAT testing – mandatory RAT completed twice a week for the first four weeks of Term 1, recommended to perform RAT if symptomatic thereafter.	5–11 years: Two doses from January 2022 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	January 2022 5–11 years: N/A 12–15 years: 97% February 2022 5–11 years: 1% 12–15 years: 97% March 2022 5–11 years: 53% 12–15 years: 99%
	QLD	N/A	N/A	N/A	N/A	N/A	January – March 2022	Positive PCR or RAT	Test if symptomatic with PCR and RAT, free RAT available for students who are symptomatic in school.	5–11 years: Two doses from January 2022 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	January 2022 5–11 years: N/A 12–15 years: 67% February 2022 5–11 years: < 1% 12–15 years: 71% March 2022 5–11 years: 22% 12–15 years: 72%
	TAS	N/A	N/A	N/A	N/A	N/A	April – May 2022	Positive PCR or RAT	Test if symptomatic with PCR and RAT, free RAT available for students who are symptomatic in school.	5–11 years: Two doses from January 2022 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	April 2022 5–11 years: 50% 12–15 years: 83% May 2022 5–11 years: 51% 12–15 years: 83%
	VIC	September – November 2021	Positive PCR	PCR testing only – advised to test if any symptoms or contact with a known case.	5–11 years: No recommendation 12–15 years: Two doses from September 2021 16–17 years: Two doses from August 2021	September 2021 5–11 years: N/A 12–15 years: < 1% October 2021 5–11 years: N/A 12–15 years: 53% November 2021 5–11 years: N/A 12–15 years: 79%	N/A	N/A	N/A	N/A	N/A

(*continued on next page*)

Table 2 (*continued*)

Country	Delta observation period					Omicron observation period				
	Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]	Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]
Canada	August – October 2021	Positive PCR	Testing eligibility determined by a healthcare professional based on symptoms, underlying medical conditions and risk of exposure to the virus.	5–11 years: No recommendation 12–17 years: Two doses from May 2021	August 2021 0–11 years: < 1% 12–17 years: 64% September 2021 0–11 years: < 1% 12–17 years: 73% October 2021 0–11 years: < 1% 12–17 years: 79%	December 2021 – February 2022	Positive PCR or RAT	PCR testing eligibility determined by a healthcare professional based on symptoms, underlying medical conditions and risk of exposure to the virus. Free RAT available in some provinces and territories.	5–11 years: Two doses from November 2021 12–17 years: Two doses from May 2021	December 2021 5–11 years: N/A 12–17 years: N/A January 2022 5–11 years: < 1% 12–17 years: 1% February 2022 5–11 years: < 1% 12–17 years: 7%
Denmark	July – September 2021	Positive PCR or RAT	Test if symptomatic or a close contact with PCR or RAT.	5–11 years: No recommendation 12–17 years: Two doses from July 2021	July 2021 5–11 years: N/A 12–15 years: N/A August 2021 5–11 years: N/A 12–15 years: 21% September 2021 5–11 years: N/A 12–15 years: 37%	December 2021 – February 2022	Positive PCR or RAT	Test if symptomatic or a close contact with PCR or RAT.	5–11 years: Two doses from November 2021 12–17 years: Two doses from July 2021	December 2021 5–11 years: 5% 12–15 years: 55% January 2022 5–11 years: 27% 12–15 years: 67% February 2022 5–11 years: 29% 12–15 years: 69%
Finland	July – September 2021	Positive PCR	Test if symptomatic or exposed with PCR. Home-based RAT available but positive RAT required confirmation by PCR.	5–11 years: No recommendation 12–15 years: Two doses from August 2021 16–17 years: Two doses from early 2021, staggered priority based on vaccine availability for older age groups	July 2021 5–11 years: N/A 12–17 years: 23% August 2021 5–11 years: N/A 12–17 years: 68% September 2021 5–11 years: N/A 12–17 years: 75%	December 2021 – February 2022	Positive PCR or RAT	Test if symptomatic or exposed with PCR or RAT. Positive RAT did not require further confirmation by PCR if household has a confirmed case and infected person's symptoms were mild.	5–11 years: Two doses from December 2021 12–15 years: Two doses from August 2021 16–17 years: Two doses from early 2021, staggered priority based on vaccine availability for older age groups	December 2021 5–11 years: 5% 12–17 years: 86% January 2022 5–11 years: 25% 12–17 years: 87% February 2022 5–11 years: 27% 12–17 years: 87%

(*continued on next page*)

Table 2 (*continued*)

Country		Delta observation period					Omicron observation period				
		Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]	Period	Case definition	Testing requirements	Vaccination recommendations[a]	Vaccination coverage[b]
United Kingdom	England	August – October 2021	Positive PCR or RAT	Test with PCR if symptomatic or RAT if non-symptomatic.	5–11 years: No recommendation 12–15 years: One dose from October 2021 16–17 years: One dose from August 2021	August 2021 5–11 years: N/A 12–15 years: N/A 16–17 years: N/A September 2021 5–11 years: N/A 12–15 years: < 1% 16–17 years: 12% October 2021 5–11 years: N/A 12–15 years: < 1% 16–17 years: 12%	December 2021 – February 2022	Positive PCR or RAT	Test with PCR if symptomatic or RAT if non-symptomatic.	5–11 years: Two doses from December 2021 12–15 years: One dose from October 2021; two doses from November 2021 16–17 years: One dose from August 2021; two doses from November 2021	December 2021 5–11 years: N/A 12–15 years: < 1% 16–17 years: 30% January 2022 5–11 years: N/A 12–15 years: 7% 16–17 years: 47% February 2022 5–11 years: N/A 12–15 years: 28% 16–17 years: 48%
	Scotland	August – October 2021	Positive PCR or RAT	Test with PCR if symptomatic or RAT if non-symptomatic.	5–11 years: No recommendation 12–15 years: One dose from October 2021 16–17 years: One dose from August 2021	August 2021 5–11 years: N/A 12–15 years: N/A 16–17 years: N/A September 2021 5–11 years: N/A 12–15 years: N/A 16–17 years: 10% October 2021 5–11 years: N/A 12–15 years: < 1% 16–17 years: 16%	December 2021 – February 2022	Positive PCR or RAT	Test with PCR if symptomatic or RAT if non-symptomatic.	5–11 years: Two doses from December 2021 12–15 years: One dose from October 2021; two doses from November 2021 16–17 years: One dose from August 2021; two doses from November 2021	December 2021 5–11 years: N/A 12–15 years: 3% 16–17 years: 32% January 2022 5–11 years: N/A 12–15 years: 35% 16–17 years: 54% February 2022 5–11 years: N/A 12–15 years: 39% 16–17 years: 57%

ACT: Australian Capital Territory; NSW: New South Wales; QLD: Queensland; TAS: Tasmania; VIC: Victoria; N/A: Data not available.

[a] Vaccination recommendation for the general 5–17-year-old population, excluding risk groups.

[b] Vaccination coverage reflects the two-dose or "fully vaccinated" (as defined by the relevant health department) coverage at the end of each month in the observation period. Age-stratified coverage rates are reported as available.

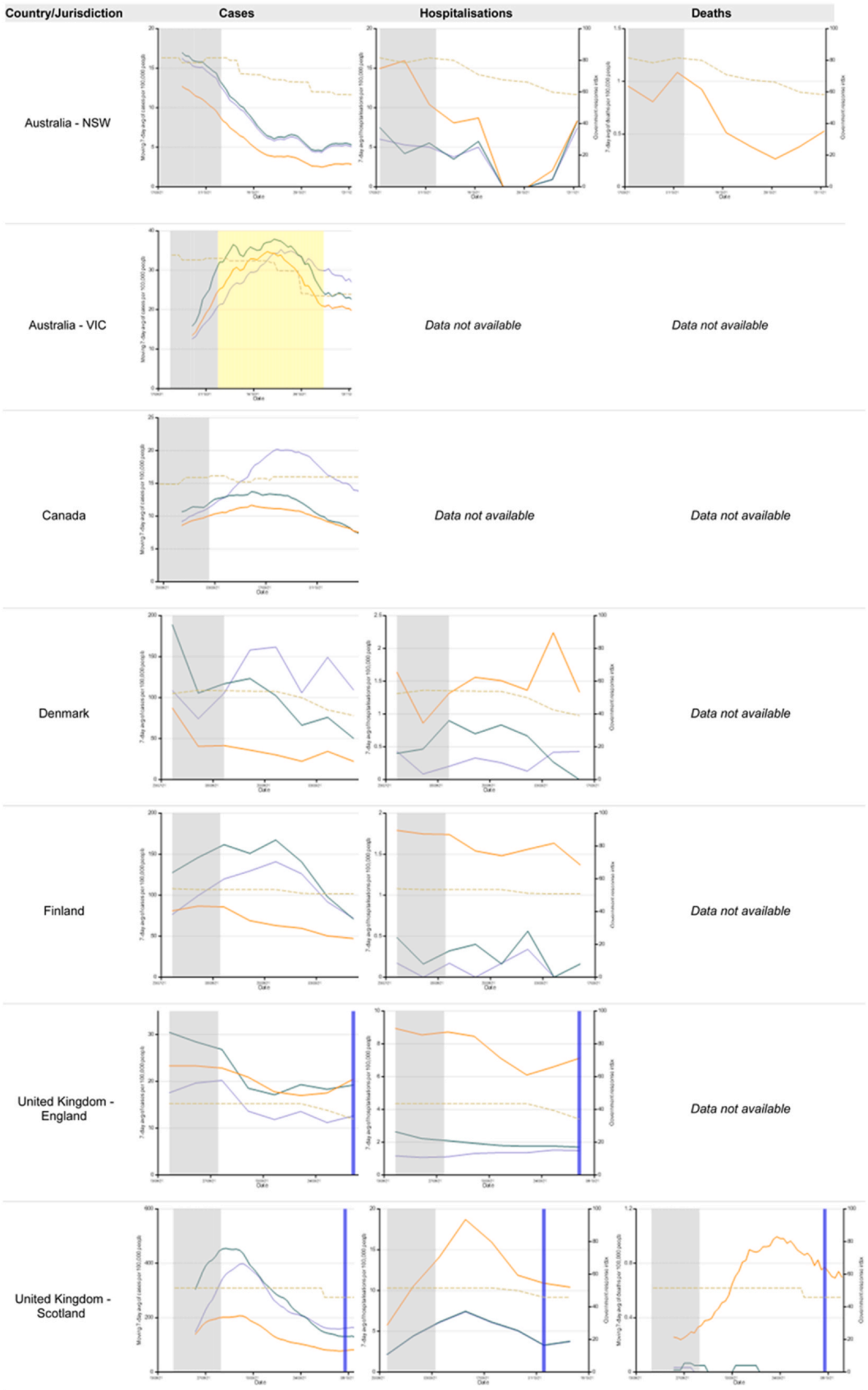

Fig. 1. Rates of SARS-CoV-2 cases, COVID-19 hospitalisations, and COVID-19 deaths per 100,000 population in Australia, Canada, Denmark, Finland, England and Scotland during the Delta period, stratified by age group. The observation period covers two weeks prior to and six weeks after school reopening (i.e. during school holiday/closure and following reopening period). Rates are presented as seven-day or moving seven-day averages depending on data availability. The lines represent primary school-aged children (purple), secondary school-aged children (green) and non-school-aged people (orange). School holidays/closures are shaded grey. Partial school reopenings (combination of in-person and online learning) are shaded yellow. Stringency of government measures is shown as a dotted line. The first confirmed cases of the Omicron variant in England and Scotland were detected towards the end of their respective observation periods and are denoted by the vertical blue lines. NSW: New South Wales; VIC: Victoria.

Table 3
Trends of SARS-CoV-2 cases and COVID-19 hospitalisations and deaths in primary and secondary school-aged children and non-school-aged people, testing rates per 1000 people, COVID-19 vaccination coverage and the Government Response Index (GRI) during the Delta and Omicron observation periods, by country and jurisdiction.

		Delta observation period						Omicron observation period					
Country		Cases	Hospitalisations	Deaths	Testing rates per 1000 people	Vaccination coverage	GRI	Cases	Hospitalisations	Deaths	Testing rates per 1000 people	Vaccination coverage	GRI
Australia	ACT	N/A	N/A	N/A	N/A	N/A	N/A	↑ then ↓	↑ then ↓	N/A	3.25–3.75[a]	≥50 y: > 99% 12–15 y: 80.4% 5–11 y: 35.2%	↓ from 50 to < 40
	NSW	↓	↓	↓	5.92–8.11[a]	≥70 y: 75.2% 12–15 y: 1% 5–11 y: 0%	↓ from > 80 to 60	↓ then ↑	Limited data	↓	3.25–3.75[a]	≥50 y: 97.4% 12–15 y: 75.0% 5–11 y (1 dose): 14.2%	↔ then ↓ from 50 to 40
	QLD	N/A	N/A	N/A	N/A	N/A	N/A	↑ in school-aged children	N/A	N/A	3.25–3.75[a]	≥50 y: 97.4% 12–15 y: 75.0% 5–11 y (1 dose): 14.2%	↓ from < 60 to 40
	TAS	N/A	N/A	N/A	N/A	N/A	N/A	↔	Fluctuated in non-school-aged	Fluctuated in non-school-aged	3.25–3.75[a]	≥50 y: > 99% 12–15 y: 80.4% 5–11 y: 35.2%	↔ at > 40
	VIC	↑ then ↓	N/A	N/A	5.92–8.11[a]	≥70 y: 75.2% 12–15 y: 1% 5–11 y: 0%	↓ from > 80 to 60	N/A	N/A	N/A	N/A	N/A	N/A
Canada		↑ then ↓	N/A	N/A	1.66–2.52	≥70 y: 92.3% 12–17 y: 58.5% 5–11 y: < 1%	↔ at ~80	↓	N/A	N/A	1.66–3.40	≥70 y: 94.9% 12–17 y: 82.6% 5–11 y: 1.5%	↔ at ~60
Denmark		↑ then fluctuated in primary school-aged ↓ in secondary school-aged ↔ in non-school-aged	↔	N/A	7.58–14.21	≥85 y: 95.9% 16–19 y: 16.7% 12–15 y: 0% 5–11 y: 0%	↔ at ~80 then ↓ to 60	↑	↔	↑ in non-school-aged	21.90–32.89	≥85 y: 96.9% 16–19 y: 84.9% 12–15 y: 61.2% 5–11 y: 5%	↔ at > 40 then ↓ to < 30
Finland		↑ then ↓ in school-aged	↔	N/A	2.73–3.97	≥70 y: 94.8% 12–17 y: 21.5% 5–11 y: 0%	↔ at ~50	↑ then ↓	↔	N/A	3.12–4.67	≥70 y: 95.9% 12–17 y: 82.6% 5–11 y: 0%	↓ from > 40 to 40
United Kingdom	England	↑	↓	N/A	11.82–16.01[a]	≥70 y: 93% < 18 y: < 1%	↔ at ~40	↓	↓	N/A	14.57–22.45[a]	≥70 y: 99% < 18 y: 23%	↔ at ~40 then ↓ to < 30
	Scotland	↓	↓	↑ then ↓ in non-school aged	11.82–16.01[a]	≥70 y: 100% 16–17 y: 10% 12–15 y: < 1% 5–11 y: < 1%	↔ at ~50 then ↓ 45	↓ then ↔	↓	↑ then ↓ in non-school-aged	14.57–22.45[a]	≥70 y:100% 16–17 y: 32% 12–15 y: 3% 5–11 y: < 1%	↑ from 40 to > 50 then ↓ to < 40

ACT: Australian Capital Territory; NSW: New South Wales; QLD: Queensland; TAS: Tasmania; VIC: Victoria; N/A: Not applicable; Vaccine coverage (two doses or "fully vaccinated") is from the beginning of the Delta and Omicron observation periods, respectively. ↑: increased, ↓: decreased, ↔: stable.

[a] National testing only.

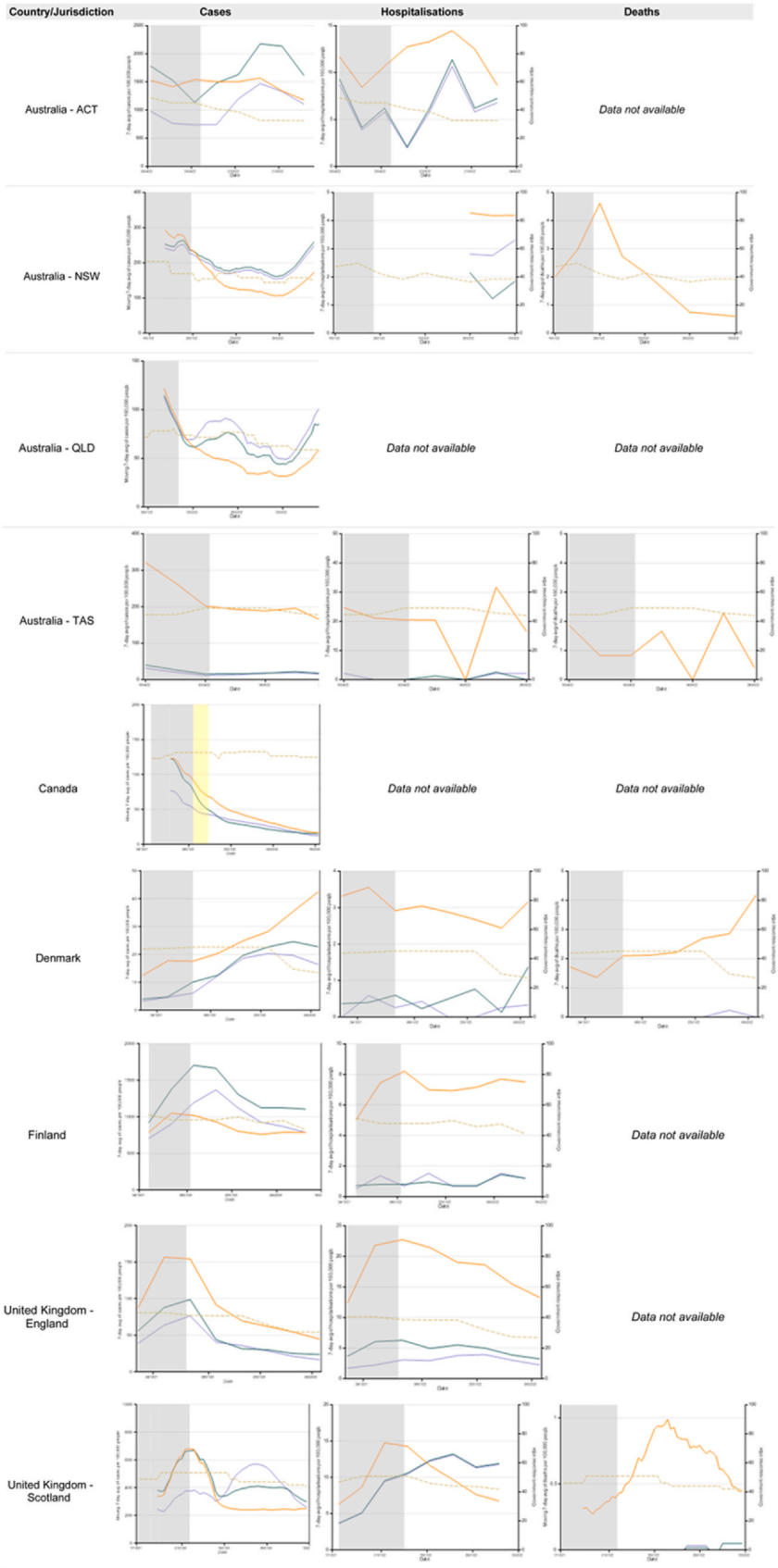

Fig. 2. Rates of SARS-CoV-2 cases, COVID-19 hospitalisations, and COVID-19 deaths per 100,000 population in Australia, Canada, Denmark, Finland, England and Scotland during the first six months of the Omicron period, stratified by age group. The observation period covers two weeks prior to and six weeks after school reopening (i.e. during school holiday/closure and following reopening period). Rates are presented as seven-day or moving seven-day averages depending on data availability. The lines represent primary school-aged children (purple), secondary school-aged children (green) and non-school-aged people (orange). School holidays/closures are shaded grey. Partial school reopenings (combination of in-person and online learning) are shaded yellow. Stringency of government measures is shown as a dotted line. ACT: Australian Capital Territory; NSW: New South Wales; QLD: Queensland; TAS: Tasmania.

Table 4
Summary of eligible studies describing SARS-CoV-2 epidemiology following school reopening.

Study	Country	Time period	Study design	Outcomes	Results	Limitations
Koirala, 2023[11]	Australia	Jun – Dec 2021	Retrospective review of surveillance data	SARS-CoV-2 case counts in 20+ year age group	Up to 14 weeks following school reopening after winter holidays: Increase in case counts up to 12 weeks, then decrease Up to 10 weeks following school reopening after spring holidays: Decrease and plateauing of case counts up to 9 weeks, then increase	Changes to school mitigation strategies, school attendance rates and adult and paediatric COVID-19 vaccine coverage were not adjusted for but described in text
Lichand, 2023[23]	Brazil	Oct – Dec 2020	Cross-sectional, using difference-in-difference analysis which matched municipalities Schools that reopened had mitigation measures: school staff wore personal protective equipment, hand sanitiser at school gate and in-person attendance was limited (e.g. at 35% capacity in regions where the severity of the pandemic was high)	SARS-CoV-2 case incidence and COVID-19 deaths in all ages	Up to 12 weeks following school reopening: No differences in case incidence (difference-in-difference of weekly new cases, −0.03; 95% CI: −0.09 to 0.03) and COVID-19 deaths (difference-in-difference, −0.003; 95% CI: −0.011 to 0.004) between municipalities with and without school reopening Findings were consistent across income levels, school infrastructure, elderly population share and local disease incidence	Adjusted for potential confounders including municipal characteristics (income, population, school and student characteristics) and baseline cases and deaths Used an intention-to-treat approach to school reopening due to a lack of detailed information of which schools effectively reopened or attendance levels School reopening occurred when mobility patterns in the general population were already high
Bignami-van Assche, 2021[24]	Canada	Aug 2020 – Jan 2021	Ecological (Montreal) and retrospective review of surveillance data (Toronto and Calgary)	SARS-CoV-2 case incidence in 20+ year age group	Up to 16 weeks following school reopening after summer holidays: Inconsistent patterns but overall increasing trend in case incidence in all age groups in Montreal, Toronto and Calgary Up to 2 weeks following school reopening after winter holidays: Increase in case incidence in most ages in Montreal and Calgary Decrease in case incidence in all ages in Toronto	No adjustment for potential confounders or testing changes
Fitzpatrick, 2022[25]	Canada	Dec 2020 – Mar 2021	Retrospective data review of cases using event study regression	SARS-CoV-2 case growth rates in 19+ year age group	Up to 4 weeks following school reopening: Lower case growth rates in 45+ year age group compared to school-aged children No change in case growth rates in 19–44 year age group	Adjusted for testing rates, population demographics, changes in PHSM and pre-event trends in case growth rates
Simetin, 2021[26]	Croatia	Feb 2020 – Mar 2021	Retrospective review of cases, hospitalisations and mortality rates	SARS-CoV-2 case incidence in all ages, COVID-19 hospitalisations and COVID-19 deaths in 26+ year age group	Throughout the study periods, there were inconsistent patterns of case incidence, hospitalisations and deaths following school reopening	No adjustment for potential confounders including testing changes
Stage, 2021[27]	Denmark, Germany and Norway	Apr – Jun 2020	Observational study which compared observed surveillance data to modelled counterfactual projection	SARS-CoV-2 case numbers COVID-19 hospitalisations in Denmark and Norway in all ages	Up to 6 weeks following school reopening: Decrease in case numbers in all ages in Denmark and Norway Decrease in hospitalisations in all ages in Germany Up to 9 weeks following school reopening: Decrease in hospitalisations in all ages in Denmark Hospitalisation data too sparse in Norway	No adjustment for potential confounders such as testing rates, socioeconomic status, household size and occupation
Buja, 2021[22]	European Union	Aug – Oct 2020	Ecological	SARS-CoV-2 reproduction number	Up to 6 weeks following school reopening: Mean reproduction number increased in 16 of 26 countries	No adjustment for potential confounders such as testing rates, age, socioeconomic status, household size and occupation

(*continued on next page*)

Table 4 (*continued*)

Study	Country	Time period	Study design	Outcomes	Results	Limitations
Somekh, 2021[28]	Israel	Aug – Dec 2020	Ecological	SARS-CoV-2 case incidence in all ages	Up to 3 weeks following first school reopening: Increase in case incidence in 10+ year age group Up to 9 weeks following second school reopening: Increase in case incidence in 10+ year age group	Adjusted for testing rates, but not socioeconomic status, household size and occupation
Mueed, 2022 (a)[29]	Pakistan	Nov 2020 – Feb 2021	Interrupted time series analysis	SARS-CoV-2 case incidence in all ages	Up to 3 weeks following school reopening: Increase in case incidence in all ages in all included cities except Karachi	No adjustment for potential confounders including testing rates
Mueed, 2022 (b)[30]	Pakistan	Nov 2020 – Mar 2021	Difference in difference analysis	SARS-CoV-2 case incidence in all ages	Up to 2 weeks following school reopening: No differences in case incidence between schools that reopened vs remained closed (difference-in-differences, 1.156 cases per day; 95% CI: −69.1 to 71.5) and between schools that reopened vs partially closed (difference-in-differences, −9.79 cases per day; 95% CI: −60.1 to 40.6)	Adjusted for changes in testing and daily time trends
Alonso, 2022[31]	Spain	Sep – Dec 2020	Retrospective review of surveillance data with modelled predictions	SARS-CoV-2 case incidence in all ages	Up to 3 months following school reopening: Increase in case incidence in 20–59 year age group Decrease in case incidence in 60–79 year age group Decrease, followed by increase in case incidence in 80+ year age group	Adjusted for confounders including testing rates and age, but not socioeconomic status, household size or occupation
Perramon, 2021[32]	Spain	Sep 2020 – Jan 2021	Retrospective review of surveillance data	SARS-CoV-2 case incidence in the general population	Up to 14 weeks following school reopening after summer holidays: Increase in case incidence in the general population up to 6 weeks, followed by decrease up to 12 weeks, then increase up to 14 weeks Up to 3 weeks following school reopening after winter holidays: Decrease in case incidence in the general population	Changes in testing rates were not adjusted for but described in text
Chernozhukov, 2021[33]	United States of America	Apr – Dec 2020	Ecological	SARS-CoV-2 case incidence and COVID-19 deaths in all ages	Up to 15 weeks following school reopening: Greater increase in cases and deaths in counties with in-person or hybrid opening compared to those with remote opening, especially for counties without any mask mandate for staff	No adjustment for contact tracing and testing strategies at the county level, age, socioeconomic status, household size and occupation
Ertem, 2021[34]	United States of America	Jul – Sep 2020	Retrospective cohort	SARS-CoV-2 case incidence in all ages	Up to 12 weeks following school reopening: No change in case incidence in most regions, except for an increase in 20+ year age group in the South and Midwest	Adjusted for testing policies, movement patterns and PHSM Excluded private schools (~10% of students)

decreased in one country (Scotland), increased in one country (Denmark) and fluctuated in one jurisdiction (Tasmania).

Hospitalisation rates varied by up to 10 times in the non-school-aged population between sites. The highest rates were in Tasmania (20 to 30 per 100,000) and England (15 to 20 per 100,000). Denmark and Finland rates were the lowest at 3 and 8 per 100,000, respectively (Fig. 1). There was marked variation in Australian jurisdictions and ranged from 4 to 30 per 100,000.

Death rates in non-school-aged population ranged from 0.5 to 4.5 per 100,000 (Fig. 1). Death rates were highest in Queensland (1 to 4.5 per 100,000) and Denmark (2 to 4 per 100,000) and lowest in Scotland (0.5 to 1 per 100,000) and Tasmania (1 to 2 per 100,000).

COVID-19 vaccination coverage rates for the elderly were very high (95–100%). During the Omicron period, coverage was highest in the ≥50-year age group in the ACT and Tasmania (> 99%) and the ≥70-year age group in Scotland (100%). In the 16–17-year age group, coverage was highest in Scotland (57%). In the 5–11 and 12–15-year age groups, coverage was highest in the ACT (68% and > 99%).

The GRI was the highest in Canada (60), 40 to 50 in Australia, and the lowest in Finland, England and Scotland (30 to 40). The GRI during Omicron was lower than Delta.

Findings from the rapid literature review summarising SARS-CoV-2 epidemiology following school reopening

The literature search resulted in a total of 19 studies, of which two were eligible. We included 12 additional studies that were not found during the initial literature search. Of the 14 included studies, five were retrospective data reviews, three were ecological studies, two were difference-in-difference analyses using surveillance data and there was one retrospective cohort study, one interrupted-time series analysis, one mixed ecological study and retrospective review, and one observational study which compared the observed data to a modelled counterfactual (Table 4). For SARS-CoV-2 case counts or incidence following school reopening, there were 12 studies - two studies reported an increase, one reported a decrease, four reported no difference and five reported inconsistent patterns. One study reported that SARS-CoV-2 reproduction numbers increased in 16 of 26 countries in the European Union up to six weeks after reopening,[22] but it was unclear whether there were testing changes during this time. Only seven studies adjusted for confounders, including testing rates, age, socioeconomic status, movement patterns and PHSM, but none adjusted for occupational status and household size. For COVID-19 hospitalisations, there were only two studies – one study reported a decrease and one reported inconsistent patterns following school reopening. For COVID-19 deaths, there were only two studies – one study reported no difference and one reported inconsistent patterns following school reopening. COVID-19 vaccination coverage was reported for one study. No studies reported excess mortality as an outcome.

Discussion

Our ecological study described the epidemiology of SARS-CoV-2 cases and COVID-19 hospitalisations and deaths in Australia, Canada, Denmark, Finland and the UK during the Delta and early Omicron periods before and immediately after schools were reopened for onsite learning. The main public health concern with schools being open for onsite learning was whether this would result in an increase in hospitalisations and deaths for those most at risk. Although children rarely experience severe disease, as confirmed in this analysis, they still transmit the virus. We found that there were no consistent patterns in case, hospitalisation or death rates, irrespective of whether schools were open for onsite learning or not. During the Delta period, there was no increase in hospitalisations except in Denmark, while noting that COVID-19 hospitalisations included both incidental cases and admissions due to COVID-19. Therefore, it is not known what proportion of the hospitalisation data reflect community cases rather than COVID-19 disease. Only two sites had data available for deaths, which decreased in NSW, but in Scotland deaths initially increased before declining. During the first two waves of Omicron, hospitalisations either declined or remained stable except one site where it increased (ACT). For deaths, two of the four sites increased (Denmark and Scotland). However, deaths then declined in Scotland after schools reopened.

Most importantly, we found that the existing trajectory for hospitalisations and deaths during the school holidays (either increasing or decreasing) continued on the same trend upon schools reopening for onsite learning. Our findings are consistent with a review including nine observational studies which was conducted in October 2022 and found that schools do not substantially contribute to community incidence, hospitalisations, or mortality but there was low certainty in their findings due to the quality of included studies.[35] Several studies found transmission of SARS-CoV-2 between school students, although this did not translate into an increase in community transmission.[10, 11] Instead, community waves corresponded to the emergence of new subvariants, which could be explained in part by waning immunity and immune escape.[36, 37] Our rapid review found an additional eight studies to the 2022 review. Seven of these studies reported increased community rates of SARS-CoV-2 following school reopening,[11, 22, 24, 28, 29, 32, 33] but only one study adjusted for testing rates,[28] while the other studies had not adjusted for important potential confounders, including testing rates which may have changed over time. Only two studies reported on hospitalisation and death rates, both of which reported inconsistent findings. As such, our study is the largest study reporting on the effect of school reopening on hospitalisations and deaths to date. Additionally, most of these studies were conducted during the ancestral variant and prior to the availability of COVID-19 vaccines and when the population was naïve, so any correlations may be less relevant in the current context of higher population immunity.

Although we did not have information on site-specific school mitigation measures, GRI levels indicate that the observed trends may have had little to do with community PHSM. This is further exemplified by the dramatic decline in COVID-19 deaths since Omicron in 2022 and 2023 (mostly due to high coverage of highly effective vaccines) despite schools returning to normal and easing of most PHSM.[38] In more recent years, quantitative sewage surveillance of SARS-CoV-2 showed considerable fluctuations over time which appeared independent of onsite schooling. These fluctuations most likely reflected changes in population immunity as new variants arise as most PHSM including school mitigation measures were eased by mid 2022, and all countries had schools open for onsite schooling from 2022.[39]

Meta-analyses have shown that children are not the primary drivers of SARS-CoV-2 transmission in households and community settings, although transmissibility may increase with newly emerging variants.[40] There are known age-related differences in the pathophysiology and immunity in children, and young children are known to clear the virus much more efficiently than adults.[41, 42] An ecological study from Portugal in the months preceding the emergence of Delta found that the addition of school closures alongside lockdowns was effective in reducing COVID-19 incidence, but the authors state that these findings may have been confounded by other factors such as subsequent changes in familial mobility trends.[43] A natural experiment in Ireland from October 2020 to January 2021, demonstrated that during stage five lockdowns schools remained open for onsite schooling for all school-age children (primary schoolers did not wear masks) and R0 declined to < 1. When lockdowns were lifted and schools were closed for a two week period over the Christmas period, R0 became greater than 1. When school reopened for onsite schooling in January 2021, R0 declined to < 1. Other studies have found an association between increased

school attendance and infections within schools, but this did not impact community tranmission, suggesting that community PHSMs would be more suitable to mitigate transmission rather than school closures. Our observations also support these findings as there were no consistent patterns of cases, hospitalisations and deaths following school reopening in all sites with both variants.

Case incidence rates varied considerably across sites. This is unsurprising given substantial differences in testing rates and is therefore likely to be a substantial underestimate of all cases. An Australian serosurvey during the Delta period found that different jurisdictions had similar evidence of prior infection across all paediatric age groups, which may suggest that varied testing recommendations and PHSM is likely to account for some of the variation in case incidence.[44] We found that overall case rates were higher in school-aged children but as there were no data on testing rates by age group, it is not possible to determine whether this is a true age difference, or reflects testing differences due to school-based testing programs. During the Delta period, of the seven sites that had case data, rates in primary school-aged children versus secondary school-aged children were higher in Canada and Denmark, lower in Victoria, Finland and England, and similar in NSW and Scotland. A serosurvey during the tail end of England's Delta period found that seroprevalence was 40% and 82% in primary and secondary school students, respectively.[45] During the Omicron period, only Queensland and Scotland had higher case rates in primary school-aged children compared to secondary school-aged children. Vaccination coverage in school-aged children varied considerably between sites during this period. However, vaccinating children may not have had a considerable effect on transmission as an analysis from England found that case incidence in secondary schools remained low when community infection rates were low, even with the introduction of the Delta variant and ineligibility of children to receive COVID-19 vaccines at the time.[46]

Differences in the case incidence between sites may also be explained by differences in school mitigations measures and other factors. The rapid review from 2022 explored the role of schools in transmission and found that secondary attack rates were low within school settings when infection prevention and control measures were in place (moderate certainty).[35] The review found that masks may reduce transmission, test-to-stay policies may not increase transmission risk compared with mandatory quarantine, cohorting and hybrid learning may make little to no difference in transmission (low certainty), and the effect of surveillance testing within schools remained inconclusive (very low certainty). A Cochrane review in 2024 of school-based mitigation measures found moderate certainty of evidence favouring the use of ventilation measures and daily testing strategies.[47] Another systematic review in 2024 on masks in children found that real-world effectiveness of child mask mandates against SARS-CoV-2 transmission or infection found no evidence of effectiveness but the studies were of low quality.[48] In Australia, a modelling study compared different school testing strategies and found that implementation of school-based asymptomatic screening could reduce both infections and loss of in-person teaching days, especially when community prevalence was high.[49] Test-to-stay strategies were as effective in reducing school infections as home quarantining close contacts, without the associated loss of in-person learning. In our study, these school-based testing strategies varied considerably by country, but it is unknown to what degree they were effective.

During Delta, the variation in hospitalisation rates were unlikely to be due to school reopening but instead due to differences in hospital testing practices and other factors not captured in this analysis, such as admission criteria and the prevalence of non-communicable diseases and other risk factors. NSW had similar rates of hospitalisation to England while having double the GRI and lower vaccination coverage in the elderly (75% vs 93%). Finland had the lowest hospitalisation rates, one of the lowest GRI, one of the lowest community testing rates, and similar vaccination coverage in the elderly as England. Denmark had one of the highest community testing rates but had similar hospitalisation rates to Finland. Scotland had two-fold higher hospitalisation rates than England despite similarly high vaccination coverage in the elderly and the GRI in Scotland being higher. The highest hospitalisations rates were low at 18 per 100,000. The highest death rates were 1 per 100,000.

Similarly, during Omicron, the variation in hospitalisation rates between sites was also likely due to differences in hospital testing practices and other factors unrelated to schools reopening. GRI did not seem to explain this variation as the GRI level was relatively similar across all sites and was lower than during Delta. Vaccination coverage in the elderly was also similar across sites. There were eight-fold differences in hospitalisation rates between Australian jurisdictions despite similarly high vaccination rates and GRI. Death rates were double between Tasmania and NSW which indicates either differences in coding or differences in care practices. For the two sites that had data for both Delta and Omicron (NSW and Scotland), hospitalisations rates were lower but deaths rates higher during Omicron in NSW, and hospitalisation rates were also lower but death rates stayed the same in Scotland. The true hospitalisation rates (after removing the "with" COVID-19 hospitalisations) were likely to be about 4 per 100,000 as the marked variation between Australian juridictions suggests that the higher rates were most likely due to testing and coding practices and admission criteria rather than reflecting any true difference in disease burden. The death rates during Omicron were higher than during Delta (4.5 vs 1 per 100,000) but were still low.

To our knowledge, this is the first multi-jurisdictional summary of the impact of school reopening on SARS-CoV-2 epidemiology. Our approach enabled comparative descriptions between countries and jurisdictions and age groups. However, our analysis has limitations. Firstly, given the ecological design of this analysis, we were unable to draw any causal inferences between school reopening and case, hospitalisation and death rates as we could not account for confounding factors and differences in coding and admission practices. Although GRI and vaccination coverage were available, other confounders such as testing rates by age group were not available. Secondly, some differences in trends occurred across sites but we were not able to ascertain the effect of school mitigation measures, which likely differed by setting. Nevertheless, we were able to describe population-level trends of SARS-CoV-2 epidemiology in the context of school reopening across multiple jurisdictions. Thirdly, we had incomplete data as we relied on publicly available datasets from government websites. This may be incomplete and likely prone to sampling bias for cases. This also limits generalising our findings to low- and middle-income countries which were not included in our analysis. Additionally, differences in coding practices and health system factors make direct comparisons across sites problematic. Nevertheless, it is the trends rather than the absolute rates which were most relevant for our analysis.

Our findings contribute to the evidence that reopening schools did not alter the pre-existing trajectory of COVID-19 hospitalisations and deaths during the Delta and early Omicron periods. Our findings show that there were no consistent patterns to case, hospitalisation or death rates in each country or jurisdiction, irrespective of whether schools were open for onsite learning or changes to PHSM. School closures were adopted by many countries as part of a suite of PHSM but in the future should only be implemented where there is strong evidence of effectiveness. Predesigned and approved study protocols, along with scenario-based planning for schools are needed to prepare for the next pandemic. The negative consequences on child health and development are profound, so understanding the role of schools in SARS-CoV-2 transmission should be a priority for pandemic preparedness and response.

Ethical statement

Ethics approval and informed consent were not required as this study used publicly available, deidentified and aggregated data from government websites. Reporting of this study complies with the STROBE checklist for observational studies.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions

DSO wrote the first draft of the manuscript. DSO and MH collated, analysed and interpreted the data. JDH provided supervision and feedback. FMR conceived the study, provided supervision, interpreted the findings and finalised the manuscript. All authors reviewed the manuscript and approved the submitted version.

Declaration of Generative AI and AI-assisted technologies in the writing process

None declared.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The Murdoch Children's Research Institute is supported by the Victorian Government's Operational Infrastructure Support Program. FMR is supported by a National Health and Medical Research Council Investigator Grant.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jinf.2024.106390.

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