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# Association Between Statewide School Closure and COVID-19 Incidence and Mortality in the US

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**IMPORTANCE** In the US, states enacted nonpharmaceutical interventions, including school closure, to reduce the spread of coronavirus disease 2019 (COVID-19). All 50 states closed schools in March 2020 despite uncertainty if school closure would be effective.

**OBJECTIVE** To determine if school closure and its timing were associated with decreased COVID-19 incidence and mortality.

**DESIGN, SETTING, AND PARTICIPANTS** US population–based observational study conducted between March 9, 2020, and May 7, 2020, using interrupted time series analyses incorporating a lag period to allow for potential policy-associated changes to occur. To isolate the association of school closure with outcomes, state-level nonpharmaceutical interventions and attributes were included in negative binomial regression models. States were examined in quartiles based on state-level COVID-19 cumulative incidence per 100 000 residents at the time of school closure. Models were used to derive the estimated absolute differences between schools that closed and schools that remained open as well as the number of cases and deaths if states had closed schools when the cumulative incidence of COVID-19 was in the lowest quartile compared with the highest quartile.

**EXPOSURES** Closure of primary and secondary schools.

**MAIN OUTCOMES AND MEASURES** COVID-19 daily incidence and mortality per 100 000 residents.

**RESULTS** COVID-19 cumulative incidence in states at the time of school closure ranged from 0 to 14.75 cases per 100 000 population. School closure was associated with a significant decline in the incidence of COVID-19 (adjusted relative change per week, −62% [95% CI, −71% to −49%]) and mortality (adjusted relative change per week, −58% [95% CI, −68% to −46%]). Both of these associations were largest in states with low cumulative incidence of COVID-19 at the time of school closure. For example, states with the lowest incidence of COVID-19 had a −72% (95% CI, −79% to −62%) relative change in incidence compared with −49% (95% CI, −62% to −33%) for those states with the highest cumulative incidence. In a model derived from this analysis, it was estimated that closing schools when the cumulative incidence of COVID-19 was in the lowest quartile compared with the highest quartile was associated with 128.7 fewer cases per 100 000 population over 26 days and with 1.5 fewer deaths per 100 000 population over 16 days.

**CONCLUSIONS AND RELEVANCE** Between March 9, 2020, and May 7, 2020, school closure in the US was temporally associated with decreased COVID-19 incidence and mortality; states that closed schools earlier, when cumulative incidence of COVID-19 was low, had the largest relative reduction in incidence and mortality. However, it remains possible that some of the reduction may have been related to other concurrent nonpharmaceutical interventions.

Viewpoint and Editorial

Author Audio Interview

Video and Supplemental content

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The novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causing coronavirus disease 2019 (COVID-19) was first identified in the US in January 2020, with subsequent spread throughout the country. In the absence of effective treatments, governors and state health officials enacted policies aimed at reducing infections through nonpharmaceutical interventions.[1] The nonpharmaceutical interventions included: school closure, nonessential business closure, restaurant and bar closure, and prohibition of gatherings with more than 10 people. With limited precedent and a paucity of evidence on the effectiveness of nonpharmaceutical interventions, policies varied markedly state to state in scope and timing.

Children infected with SARS-CoV-2 may be asymptomatic or have mild symptoms indistinguishable from other common upper respiratory tract infections,[2,3] allowing them to spread the virus when they feel well. Children are often key transmitters in viral epidemics like influenza[4] because of spending prolonged periods in close proximity to other children at school and during physical activities. Prior studies have demonstrated an association between school closure and reduced transmission of viral respiratory illnesses.[5-8] Given concerns that children represented a significant vector for SARS-CoV-2, all states closed schools despite a lack of evidence supporting the effectiveness of school closure in curbing the spread of this virus.

Schools promote child education, growth, development, and overall well-being.[9] Knowing whether school closure is effective in reducing infections is critical to reduce the negative effects of continued school closure on child health if school closure is ineffective. This national study assessed the association between school closure and its timing with subsequent COVID-19 incidence and mortality, with the hypothesis that any association between school closure and incidence and mortality would be strongest in states that closed schools early when the cumulative incidence of disease was low.

## Key Points

**Question** Was statewide school closure associated with decreased incidence and mortality for coronavirus disease 2019 (COVID-19)?

**Findings** In this US population–based time series analysis conducted between March 9, 2020, and May 7, 2020, school closure was associated with a significant decline in both incidence of COVID-19 (adjusted relative change per week, −62%) and mortality (adjusted relative change per week, −58%). In a model derived from this analysis, it was estimated that closing schools when the cumulative incidence of COVID-19 was in the lowest quartile compared with the highest quartile was associated with 128.7 fewer cases per 100 000 population over 26 days and with 1.5 fewer deaths per 100 000 population over 16 days.

**Meaning** There was a temporal association between statewide school closure and lower COVID-19 incidence and mortality, although some of the reductions may have been related to other concurrent nonpharmaceutical interventions.

## Methods

The study was a population-based time series analysis of all 50 US states conducted between March 9, 2020, and May 7, 2020. This period allowed for at least 6 weeks of data collection after school closures in each state. The institutional review board at Cincinnati Children's Hospital Medical Center deemed this study was not subject to oversight given the use of publicly available data.

### Independent Variables

Associations of primary and secondary school closure (kindergarten-grade 12) and its timing with outcomes of interest were examined. Because school closure timing varied relative to disease progression in the state, we examined the cumulative incidence of COVID-19 (defined as total number of cases per 100 000 residents) grouped in quartiles by the date the school closure policy went into effect.

The analysis was performed by quartiles of cumulative incidence of COVID-19 instead of as a continuous variable because the relationships between baseline cumulative incidence and outcomes were not assumed to be linear.

### Outcome Measures

Daily COVID-19 incidence and daily mortality per 100 000 residents in each state were estimated using publicly available data from the Johns Hopkins University School of Public Health.[10] This source aggregates data from the US Centers for Disease Control and Prevention (CDC) as well as from state and local public health departments. In accordance with CDC guidelines, confirmed COVID-19 cases include presumptive positive cases and probable cases, and death totals include confirmed and probable cases. The denominator for the outcome measures was the state population from the 2018 American Community Survey.[11]

### Covariates

State characteristics were included as covariates in the models to assess the independent associations with school closure. For each state, the following non-school-related nonpharmaceutical intervention covariates were considered: stay-at-home or shelter-in-place order, nonessential business closure, restaurant and bar closure, and prohibition of gatherings with more than 10 people. These nonpharmaceutical interventions were included based on the policy effective date (eTable 1 in the Supplement) plus a lag period to allow for any potential policy-related effects on daily COVID-19 incidence and mortality (eFigure in the Supplement). Potential effects associated with subsequent lifting of nonpharmaceutical interventions occurred outside the study period and thus are not included (eMethods in the Supplement).

SARS-CoV-2 testing rates varied by state and throughout the study period. To account for this variation, state-level COVID-19 testing[12] (calculated daily as the cumulative number of tests per 1000 residents) was modeled as a categorical variable. State measures of urban population density (a measure of the state's population density combined with the percentage of residents living in urban areas),[11] percentage of the state's population with obesity,[13] percentage of the state's population aged 15 years or younger,[11] percentage of the state's population aged 65 years or older,[11] and the number of nursing home residents per 1000 people were included.[14] The CDC social vulnerability index also was included; this index accounts for multiple factors, including socioeconomic status, household composition, disability status, race and ethnicity composition, English-language proficiency, housing type, and transportation access, to assess a community's preparedness for a natural disaster or illness outbreak.[15] Many of these factors have been associated with COVID-19 disease, mortality, or both. All covariates are described in detail in the eMethods in the Supplement.

### Statistical Analysis

Interrupted time series analyses were used to compare the daily change in outcomes (daily COVID-19 incidence and mortality) before and after school closure. Acknowledging that school closure and other nonpharmaceutical interventions would not have immediate effects on COVID-19 incidence and mortality, estimates were used to determine when school-based exposure could be expected to lead to changes in COVID-19 incidence and associated mortality (eFigure in the Supplement). A time from exposure to symptom onset of 5 days was assumed per Lauer et al.[16] Given the early emphasis (and some state restrictions[17-25]) on limiting testing to hospitalized patients, time to diagnosis was defined as time between symptom onset and hospitalization (7 days).[26] For school closure, given the low documented prevalence of COVID-19 in children, an additional period was included for a child to infect an adult, assuming a child exposed at school could expose an adult prior to symptom onset and within 4 days. The analyses for the mortality outcome assumed 17 days from symptom onset to death.[27] For details on lag period calculations, see the eMethods in the Supplement.

Daily COVID-19 incidence and mortality were modeled using negative binomial regression. Interactions between school closure and all included covariates were explored because school closure may affect at-risk communities differently.[9] Given the large number of covariates and interactions considered, a single parsimonious model for each outcome was created selecting covariates from the primary model using a stepwise regression approach, with entry and removal criteria specified as a *P* value of <.20. Because factors associated with COVID-19 incidence and mortality may vary with school closure, covariate selection was completed independently during and after the lag period (eMethods in the Supplement).

Results are reported as the relative change in the outcome from week to week. Adjusted changes in both daily COVID-19 incidence and daily mortality over time are graphically displayed for all states by quartile of cumulative incidence at the time of school closure. To estimate absolute differences associated with school closure, the projected COVID-19 incidence and mortality if schools had remained open were compared with the modeled incidence and mortality with school closure. Both linear and exponential assumptions were used to project COVID-19 incidence and mortality if schools had remained open (eMethods in the Supplement). To estimate absolute differences in outcomes based on school closure timing, model parameters were used to estimate the absolute differences in the number of COVID-19 cases and deaths for a state that closed schools when the cumulative incidence of COVID-19 was in the lowest quartile compared with a state that closed schools when the cumulative incidence of COVID-19 was in the highest quartile (eMethods in the Supplement).

Analyses were performed using SAS version 9.4 (SAS Institute Inc) and 2-sided *P* values of <.05 were considered statistically significant.

### Sensitivity Analyses Around the Lag Period

Because the COVID-19 incidence and mortality lag period estimates are based on emerging evidence, the sensitivity analyses examined the robustness of findings if the lag period was shorter (10 days for incidence and 20 days for mortality) or longer (21 days for incidence and 33 days for mortality). Detailed methods and rationale for the sensitivity ranges appear in the eMethods and eFigure in the Supplement.

## Results

All 50 states closed schools between March 13, 2020, and March 23, 2020. The cumulative incidence of COVID-19 at the time of school closure ranged from 0 to 14.75 cases per 100 000 population. State characteristics by COVID-19 incidence quartile at the time of school closure appear in **Table 1**. There was wide variability in the testing rate per 1000 residents and in the number of nursing home residents per 1000 people. There was less variability in the percentage of the state populations for the number of nonpharmaceutical interventions enacted; 39 states enacted all 4 nonpharmaceutical interventions examined.

States in the highest quartile of cumulative incidence of COVID-19 at the time of school closure enacted multiple nonpharmaceutical interventions over a shorter period. The median time from school closure to the last enacted nonpharmaceutical intervention was 5 days (interquartile range, 2.5-8 days). In comparison, states in the lowest quartile of cumulative incidence of COVID-19 at the time of school closure enacted nonpharmaceutical interventions over a longer period. The median time from school closure to the last enacted nonpharmaceutical intervention was 12 days (interquartile range, 8-14 days; Table 1).

### COVID-19 Incidence

The observed case rates of COVID-19 in each state (relative to the day of school closure by cumulative incidence) and the 16-day lag period are depicted in **Figure 1**A. In the unadjusted analyses during the period prior to potential effects of school closure (ie, during the lag period), the overall relative change in COVID-19 incidence per week was 220% (95% CI, 205% to 236%). The unadjusted relative change per week associated with school closure was −68% (95% CI, −70% to −66%). The unadjusted effect size associated with school closure varied by cumulative COVID-19 incidence at the time of school closure, with states in the highest quartile of cumulative COVID-19 incidence having the smallest relative effect size (**Table 2**).

Table 1. State Characteristics by Coronavirus Disease 2019 (COVID-19) Incidence Quartile at the Time of School Closure

| States by COVID-19 incidence quartile at the time of school closure | Cumulative incidence per 100 000 residents | Date of school closure in March | Maximum testing rate per 1000 residents[a] | Percentage of state population | | No. of nursing home residents per 1000 people | Percentage of state population with obesity[b] | Urban density as residents/square mile[c] | Social vulnerability index[d] | No. of non-school-related NPIs enacted[e] | Days between school closure and enactment of last NPI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Aged ≤15 y | Aged ≥65 y | | | | | | |
| **Lowest quartile** | | | | | | | | | | | |
| Median (IQR) | 0.48 (0.26-0.57) | | 20.5 (16.0-25.0) | 18.5 (18.2-19.5) | 15.6 (14.6-16.5) | 3.8 (3.3-5.1) | 33.0 (30.4-34.8) | | 46.9 (44.5-58.5) | 4 (4-4) | 12 (8-14) |
| West Virginia | 0 | 16 | 31.4 | 16.9 | 18.3 | 5.1 | 39.5 | <50 | 51.5 | 4 | 8 |
| North Dakota | 0.13 | 16 | 54.3 | 19.6 | 13.9 | 7.4 | 35.1 | <50 | 20.1 | 2 | 14 |
| Alaska | 0.14 | 16 | 33.0 | 21.2 | 10.5 | 0.8 | 29.5 | <50 | 45.9 | 4 | 12 |
| Arizona | 0.26 | 16 | 16.0 | 19.5 | 16.5 | 1.6 | 29.5 | 50-100 | 72.1 | 4 | 15 |
| North Carolina | 0.37 | 16 | 16.9 | 18.7 | 15.1 | 3.5 | 33 | 100-150 | 58.5 | 4 | 14 |
| Kentucky | 0.47 | 16 | 17.7 | 18.9 | 15.1 | 5.1 | 36.6 | 50-100 | 55.8 | 4 | 10 |
| Oklahoma | 0.48 | 17 | 22.2 | 20.4 | 14.6 | 4.7 | 34.8 | <50 | 62.6 | 2 | 8 |
| Hawaii | 0.49 | 16 | 25.0 | 18.2 | 17.1 | 2.4 | 24.9 | 100-150 | 46.9 | 4 | 9 |
| Michigan | 0.53 | 16 | 24.8 | 18.1 | 15.9 | 3.8 | 33 | 50-100 | 45.6 | 4 | 8 |
| South Carolina | 0.56 | 15 | 15.6 | 18.4 | 16.4 | 3.4 | 34.3 | 100-150 | 61.8 | 4 | 22 |
| Ohio | 0.58 | 17 | 15.1 | 18.5 | 15.6 | 6.3 | 34 | >150 | 44.5 | 4 | 6 |
| Virginia | 0.58 | 16 | 14.6 | 18.4 | 14.3 | 3.3 | 30.4 | 100-150 | 34.4 | 3 | 14 |
| Pennsylvania | 0.60 | 16 | 20.5 | 17.2 | 16.8 | 6 | 30.9 | >150 | 41.1 | 4 | 16 |
| **Second lowest quartile** | | | | | | | | | | | |
| Median (IQR) | 0.79 (0.71-0.87) | | 19.7 (17.6-26.8) | 19.5 (18.4-19.7) | 15.2 (14.3-16.6) | 4.5 (3.7-5.7) | 33.8 (30.7-35.1) | | 46.0 (34.1-67.2) | 4 (4-4) | 10 (8.5-14) |
| Kansas | 0.62 | 17 | 15.4 | 20.5 | 14.5 | 5 | 34.4 | <50 | 38.6 | 4 | 11 |
| Montana | 0.67 | 16 | 19.4 | 18.2 | 17.2 | 4 | 26.9 | <50 | 26.2 | 4 | 10 |
| Maryland | 0.68 | 16 | 24.8 | 18.6 | 14.2 | 4.1 | 30.9 | >150 | 39.1 | 4 | 14 |
| Iowa | 0.73 | 16 | 21.2 | 19.4 | 15.6 | 7.5 | 35.3 | <50 | 29.1 | 3 | 10 |
| Arkansas | 0.74 | 17 | 20.1 | 19.6 | 15.7 | 5.8 | 37.1 | <50 | 65.5 | 2 | 9 |
| Louisiana | 0.77 | 13 | 43.0 | 19.8 | 13.9 | 5.6 | 36.8 | 50-100 | 72 | 4 | 10 |
| New Mexico | 0.81 | 16 | 40.9 | 19.6 | 16 | 2.7 | 32.3 | <50 | 77.2 | 4 | 7 |
| Nevada | 0.82 | 15 | 17.6 | 19.2 | 14.8 | 1.8 | 29.5 | <50 | 68.9 | 4 | 16 |
| Delaware | 0.84 | 16 | 28.8 | 17.8 | 17.2 | 4.4 | 33.5 | >150 | 44.7 | 4 | 8 |
| Maine | 0.90 | 15 | 17.6 | 15.6 | 19 | 4.5 | 30.4 | <50 | 29.5 | 4 | 17 |
| Indiana | 0.90 | 19 | 18.8 | 19.6 | 14.4 | 5.8 | 34.1 | 100-150 | 47.3 | 4 | 5 |
| Texas | 0.93 | 19 | 16.3 | 21.8 | 11.6 | 3.3 | 34.8 | 50-100 | 65.2 | 4 | 14 |
| **Second highest quartile** | | | | | | | | | | | |
| Median (IQR) | 1.28 (1.16-1.60) | | 23.3 (19.8-27.0) | 18.8 (17.6-20.1) | 15.1 (14.4-15.8) | 4.6 (3.5-5.3) | 30.7 (29.9-32.5) | | 42.6 (30.5-57.3) | 4 (3-4) | 11 (7-15) |
| Nebraska | 0.94 | 16 | 19.8 | 20.8 | 14.4 | 6 | 34.1 | <50 | 33.7 | 2 | 18 |
| Oregon | 0.96 | 16 | 17.3 | 17.6 | 16.5 | 1.8 | 29.9 | <50 | 52.5 | 3 | 7 |

(continued)

Table 1. State Characteristics by Coronavirus Disease 2019 (COVID-19) Incidence Quartile at the Time of School Closure (continued)

| States by COVID-19 incidence quartile at the time of school closure | Cumulative incidence per 100 000 residents | Date of school closure in March | Maximum testing rate per 1000 residents[a] | Percentage of state population | | No. of nursing home residents per 1000 people | Percentage of state population with obesity[b] | Urban density as residents/square mile[c] | Social vulnerability index[d] | No. of non–school-related NPIs enacted[e] | Days between school closure and enactment of last NPI |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Aged ≤15 y | Aged ≥65 y | | | | | | |
| Florida | 1.05 | 17 | 23.9 | 16.6 | 19.4 | 3.5 | 30.7 | >150 | 60.7 | 4 | 17 |
| South Dakota | 1.16 | 16 | 23.3 | 20.8 | 15.1 | 6.9 | 30.1 | <50 | 32.6 | 1 | 7 |
| Illinois | 1.26 | 17 | 29.6 | 18.8 | 14.3 | 5.2 | 31.8 | >150 | 48.6 | 4 | 4 |
| New Hampshire | 1.27 | 16 | 21.4 | 15.8 | 16.5 | 4.8 | 29.6 | 50-100 | 13.8 | 4 | 11 |
| Utah | 1.28 | 16 | 44.2 | 25.3 | 10.3 | 1.7 | 27.8 | <50 | 30.2 | 3 | 11 |
| Minnesota | 1.39 | 18 | 17.6 | 19.5 | 14.6 | 4.5 | 30.1 | <50 | 27.8 | 4 | 9 |
| Wisconsin | 1.59 | 18 | 17.7 | 18.4 | 15.6 | 4.2 | 32 | 50-100 | 30.5 | 4 | 7 |
| Alabama | 1.60 | 19 | 23.7 | 18.6 | 15.7 | 4.6 | 36.2 | 50-100 | 61.8 | 4 | 15 |
| Mississippi | 1.67 | 19 | 27.0 | 20 | 14.5 | 5.3 | 39.5 | <50 | 74.1 | 4 | 15 |
| Connecticut | 1.90 | 17 | 32.4 | 17 | 15.8 | 6.3 | 27.4 | >150 | 42.6 | 4 | 9 |
| Georgia | 1.93 | 18 | 21.1 | 20.1 | 12.8 | 3.2 | 32.5 | 100-150 | 57.3 | 4 | 16 |
| **Highest quartile** | | | | | | | | | | | |
| Median (IQR) | 3.30 (2.95-11.37) | | 30.2 (19.5-43.5) | 18.7 (17-19.2) | 15.1 (14.6-15.4) | 4.1 (2.8-5.5) | 27.7 (25.8-28.9) | | 41.5 (36.0-51.9) | 4 (4-4) | 5 (2.5-8) |
| California | 2.43 | 19 | 21.5 | 19.3 | 13.3 | 2.6 | 25.8 | >150 | 65.4 | 4 | 0 |
| Vermont | 2.88 | 18 | 29.5 | 15.4 | 17.8 | 3.9 | 27.5 | <50 | 20.1 | 4 | 7 |
| Massachusetts | 2.88 | 16 | 51.5 | 16.5 | 15.2 | 5.7 | 25.7 | >150 | 40.1 | 4 | 8 |
| New Jersey | 3.01 | 18 | 33.0 | 18.3 | 15 | 5 | 25.7 | >150 | 44.4 | 4 | 3 |
| Missouri | 3.07 | 23 | 17.0 | 18.8 | 15.5 | 6.2 | 35 | 50-100 | 41.1 | 2 | 14 |
| Wyoming | 3.09 | 19 | 20.7 | 19.9 | 14.7 | 4.2 | 29 | <50 | 27.8 | 2 | 1 |
| Tennessee | 3.50 | 20 | 35.5 | 18.7 | 15.3 | 4 | 34.4 | 100-150 | 52.8 | 4 | 11 |
| Idaho | 4.03 | 23 | 18.3 | 21.6 | 14.8 | 2 | 28.4 | <50 | 38.9 | 4 | 2 |
| Rhode Island | 10.03 | 23 | 77.9 | 16.2 | 15.7 | 7.4 | 27.7 | >150 | 51 | 4 | 5 |
| New York | 12.72 | 18 | 55.6 | 17.5 | 15.1 | 5.2 | 27.6 | >150 | 54.5 | 4 | 5 |
| Colorado | 12.73 | 23 | 16.5 | 19 | 13.1 | 2.9 | 23 | <50 | 33 | 4 | 3 |
| Washington | 14.75 | 17 | 30.8 | 18.7 | 14.5 | 2.2 | 28.7 | 50-100 | 41.9 | 4 | 8 |

Abbreviations: IQR, interquartile range; NPIs, nonpharmaceutical interventions.

[a] Calculated daily by dividing the cumulative number of tests performed in a state by the state population; modeled as a categorical variable. The minimum testing rate was less than 0.1 tests per 1000 residents and occurred on the first day of testing for every state. The maximum testing rate was the testing rate on the last day of the study period.

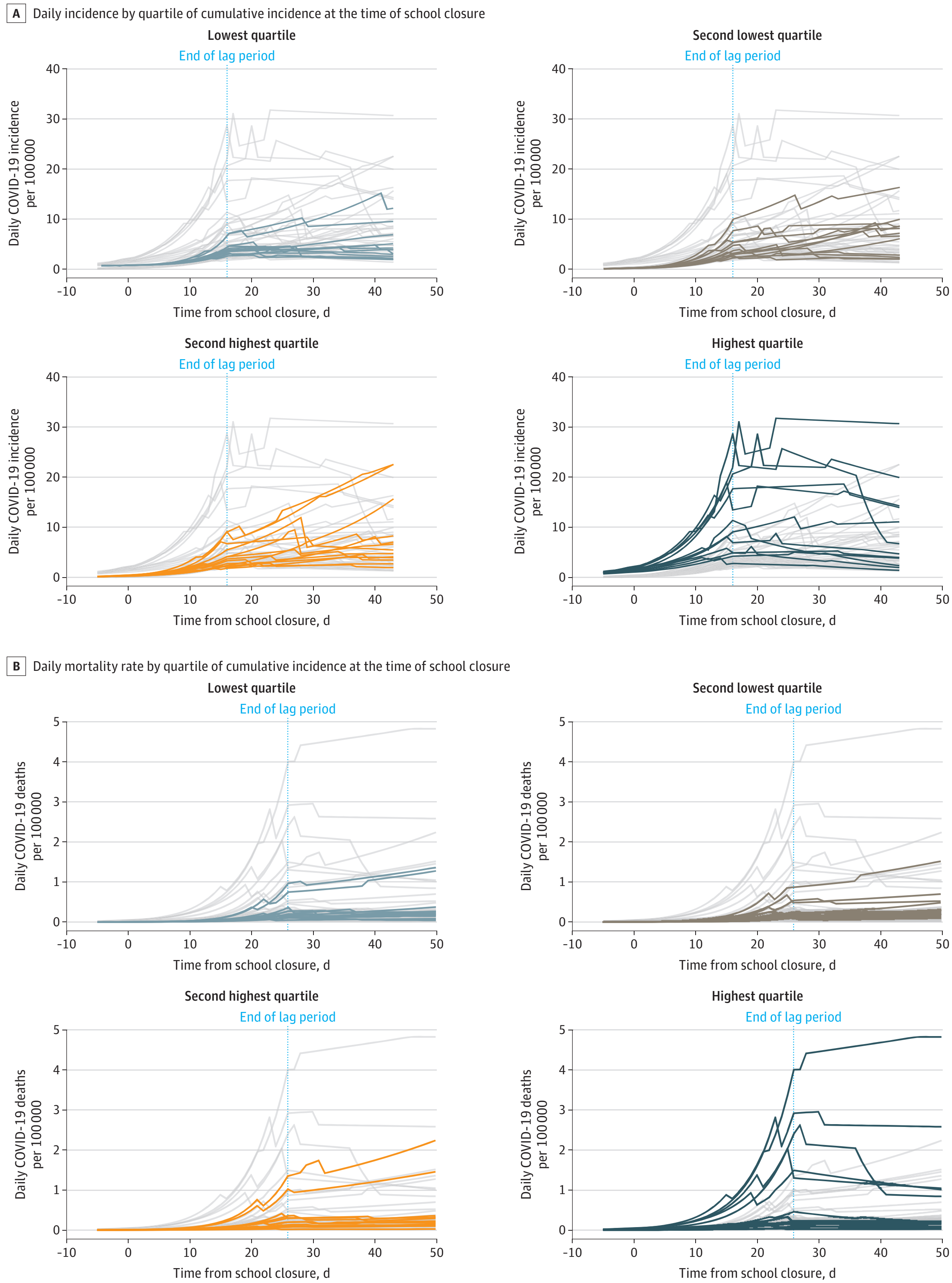
[b] Defined as a body mass index (calculated as weight in kilograms divided by height in meters squared) of 30 or greater.

[c] A measure of the state's population density combined with the percentage of residents living in urban areas; examined as a categorical variable.

[d] US Centers for Disease Control and Prevention measure of a community's preparedness for a natural disaster or illness outbreak by accounting for socioeconomic status, household composition, disability status, race and ethnicity composition, English-language proficiency, housing type, and transportation access. Scale is 0 to 100 with lower numbers indicating better preparedness for a natural disaster or illness outbreak; the national median is 50.

[e] Ranged between 1 and 4. The NPIs examined included stay-at-home or shelter-in-place order, nonessential business closure, restaurant and bar closure, and prohibition of gatherings with more than 10 people. All states enacted at least 1 non–school-related NPI.

Figure 1. Observed Daily COVID-19 Incidence and Mortality by Cumulative Incidence Quartile at the Time of School Closure




COVID-19 indicates coronavirus disease 2019.

Table 2. COVID-19 Incidence and Mortality and Effect Size Associated With School Closure

| Model | All States | COVID-19 cumulative incidence quartile at the time of school closure | | | |
|---|---|---|---|---|---|
| | | Lowest | Second lowest | Second highest | Highest |
| **COVID-19 incidence** | | | | | |
| Period before school closure (during lag period: days 1-16) | | | | | |
| Overall new cases per 100 000 residents, No. | 71 | 28 | 29 | 39 | 151 |
| New cases per 100 000 residents per state, median (IQR) | 19 (17 to 52) | 16 (15 to 19) | 21 (18 to 34) | 30 (17 to 45) | 73 (51 to 107) |
| Unadjusted relative change per week, % (95% CI) | 220 (205 to 236) | 324 (284 to 369) | 259 (225 to 296) | 195 (170 to 223) | 135 (114 to 157) |
| Composite[a] adjusted[b] relative change per week, % (95% CI) | 265 (231 to 303) | 387 (327 to 456) | 339 (285 to 402) | 240 (200 to 286) | 143 (117 to 173) |
| Period after school closure (after lag period: days 17-42) | | | | | |
| Overall new cases per 100 000 residents, No. | 238 | 157 | 160 | 183 | 387 |
| New cases per 100 000 residents per state, median (IQR) | 116 (79 to 217) | 79 (69 to 122) | 124 (84 to 257) | 126 (110 to 198) | 121 (90 to 764) |
| Composite[c] adjusted[b] relative change per week, % (95% CI) | 10 (1 to 18) | 7 (-2 to 18) | 16 (5 to 28) | 20 (9 to 32) | -4 (-12 to 5) |
| Relative change per week associated with school closure, % (95% CI) | | | | | |
| Unadjusted | -68 (-70 to -66) | -77 (-80 to -73) | -69 (-74 to -65) | -62 (-67 to -56) | -61 (-66 to -55) |
| Adjusted[b] | -62 (-71 to -49) | -72 (-79 to -62) | -66 (-75 to -54) | -55 (-66 to -39) | -49 (-62 to -33) |
| **COVID-19 mortality** | | | | | |
| Period before school closure (during lag period: days 1-26) | | | | | |
| Overall new deaths per 100 000 residents, No. | 7 | 3 | 3 | 3 | 14 |
| New deaths per 100 000 residents per state, median (IQR) | 2 (1 to 4) | 1 (1 to 2) | 2 (1 to 3) | 2 (1 to 3) | 6 (2 to 10) |
| Unadjusted relative change per week, % (95% CI) | 171 (160 to 184) | 212 (184 to 243) | 182 (157 to 210) | 169 (148 to 192) | 129 (113 to 146) |
| Composite[a] adjusted[d] relative change per week, % (95% CI) | 186 (175 to 197) | 243 (212 to 277) | 224 (195 to 258) | 172 (152 to 195) | 120 (105 to 136) |
| Period after school closure time (after lag period: days 27-42) | | | | | |
| Overall new deaths per 100 000 residents, No. | 9 | 7 | 6 | 7 | 15 |
| New deaths per 100 000 residents per state, median (IQR) | 3 (2 to 9) | 3 (2 to 4) | 3 (2 to 11) | 4 (2 to 5) | 4 (2 to 27) |
| Composite[c] adjusted[d] relative change per week, % (95% CI) | 2 (-8 to 14) | 6 (-7 to 20) | 10 (-4 to 25) | 7 (-6 to 22) | -12 (-21 to -1) |
| Relative change per week associated with school closure, % (95% CI) | | | | | |
| Unadjusted | -64 (-67 to -61) | -69 (-73 to -64) | -63 (-68 to -57) | -63 (-68 to -57) | -61 (-66 to -56) |
| Adjusted[d] | -58 (-67 to -46) | -64 (-73 to -52) | -61 (-71 to -47) | -54 (-65 to -39) | -53 (-63 to -40) |

Abbreviations: COVID-19, coronavirus disease 2019; IQR, interquartile range.

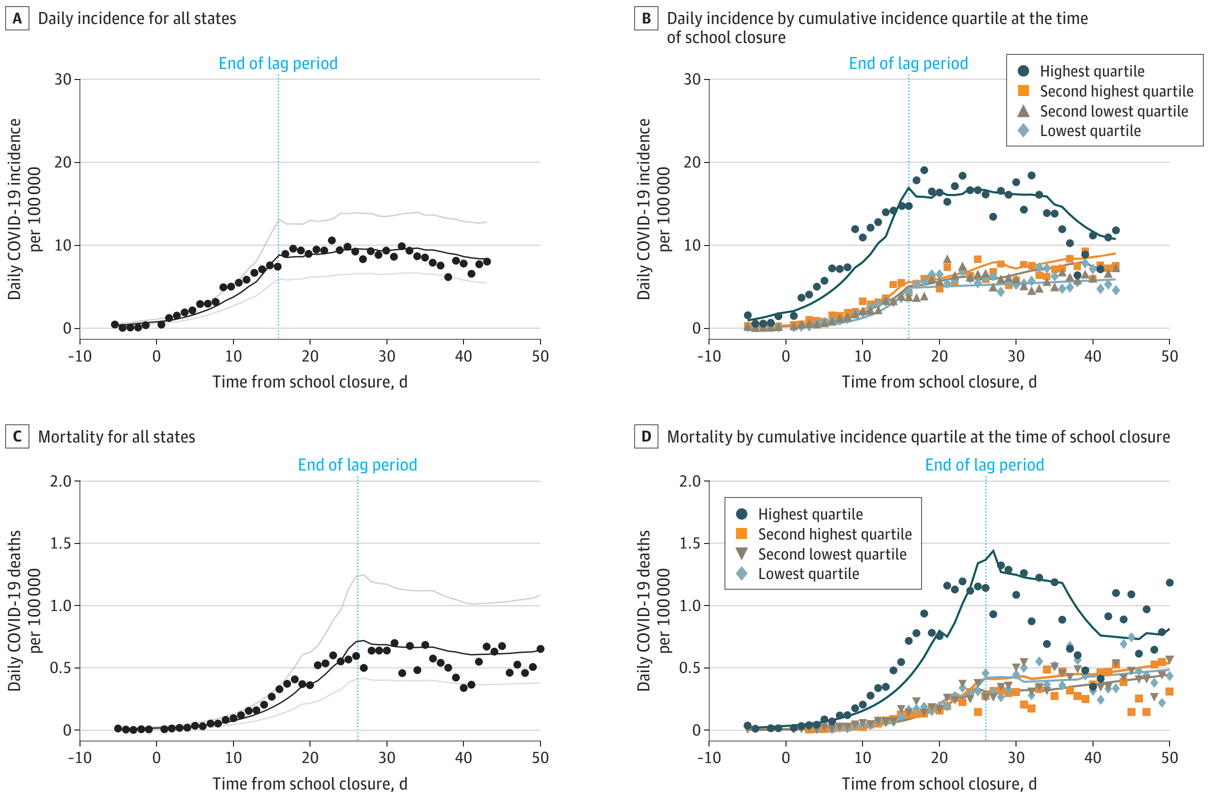
[a] Indicates the overall increase. The components of each covariate attributing to the overall change before school closure are presented in eTable 2 (incidence) and eTable 5 (mortality) in the Supplement.

[b] Adjusted for all model components retained in incidence model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and US Centers for Disease Control and Prevention (CDC) social vulnerability index; before school closure: stay-at-home or shelter-in-place order, restaurant and bar closure, testing rate per 1000 residents, and urban density; after school closure: testing rate per 1000 residents, stay-at-home or shelter-in-place order, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density).

[c] Based on the linear combination of the following model parameter estimates: relative change before school closure, the effect associated with school closure, and all other non–school closure effects over time.

[d] Adjusted for all model components retained in mortality model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and CDC social vulnerability index; before school closure: stay-at-home or shelter-in-place order, prohibition of gatherings with >10 people, restaurant and bar closure, percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density; after school closure: restaurant and bar closure, number of nursing home residents per 1000 people, and urban density).

Figure 2. Modeled Association of School Closure With Coronavirus Disease 2019 (COVID-19) Incidence and Mortality




The data markers indicate the national unadjusted daily rates. The lines depict aggregated national daily rates adjusted for each state's unique set of testing and demographic characteristics on each day of the study period with 95% CIs depicted by gray lines. Six weeks after school closure, states in the lowest quartile had fewer new cases and fewer deaths compared with the states in the highest quartile. Panels A and B were adjusted for all model components retained in the incidence model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and US Centers for Disease Control and Prevention [CDC] social vulnerability index; before school closure: stay-at-home or shelter-in-place order, restaurant and bar closure, testing rate per 1000 residents, and urban density; after school closure: testing rate per 1000 residents, stay-at-home or shelter-in-place order, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density). Panels C and D were adjusted for all model components retained in the mortality model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and CDC social vulnerability index; before school closure: stay-at-home or shelter-in-place order, prohibition of gatherings with >10 people, restaurant and bar closure, percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density; after school closure: restaurant and bar closure, number of nursing home residents per 1000 people, and urban density).

In the adjusted analyses during the period prior to potential effects of school closure (ie, during the lag period), the relative change in COVID-19 incidence per week was 265% (95% CI, 231% to 303%; Table 2). The overall combined composite relative weekly change in COVID-19 incidence after school closure was 10% (95% CI, 1% to 18%). This composite change after school closure is a combination of the changes associated with school closure and other non-school-related changes during the period after school closure and is visually depicted as the change after school closure in **Figure 2**. When examining only school closure, it was associated with a relative change in COVID-19 incidence per week of −62% (95% CI, −71% to −49%; Table 2).

The states that closed early, when the cumulative incidence of COVID-19 was lowest, had the greatest relative change per week associated with school closure (−72% [95% CI, −79% to −62%]). States that were slowest to close schools and had the highest cumulative incidence of COVID-19 had a relative change per week associated with school closure of −49% (95% CI, −62% to −33%; Table 2 and Figure 2). The full model with all covariate estimates appears in eTable 2 in the Supplement. The relative change associated with school closure for COVID-19 incidence varied significantly by the testing rate per 1000 residents, by the percentage of the state's population aged 65 years or older, by the number of nursing home residents per 1000 people, and by urban density. Information on interpreting relative weekly changes appears in the eMethods in the Supplement.

The absolute effects associated with school closure during the 26-day period after school closure (days 17-42), which were calculated using model estimates with the assumption of linear growth, yielded 638.7 cases per 100 000 that would have occurred if schools had remained open (**Table 3**). Compared with the 214.8 cases per 100 000 estimated from the school closure model, the absolute difference associated with school closure was 423.9 (95% CI, 375.0 to 463.7) cases per

Table 3. Estimated Absolute Differences in COVID-19 Cases[a] Between Period of School Closure and Schools Remaining Open Using Linear Projection[b]

| | COVID-19 cases per 100 000 in average state[c,d] | Estimated absolute difference (95% CI) in cases per 100 000 by quartile of COVID-19 cumulative incidence at school closure[d] | | | |
|---|---|---|---|---|---|
| | | Lowest | Second lowest | Second highest | Highest |
| Schools remain open (projected) | | | | | |
| Before school closure (during lag period: days 1-16) | 37.0 (30.5 to 45.0) | 23.3 (17.2 to 31.7) | 31.8 (23.1 to 43.7) | 32.6 (24.1 to 44.1) | 81.2 (59.5 to 110.7) |
| After lag period (days 17-42) | 638.7 (604.5 to 686.9) | 546.2 (509.0 to 598.1) | 670.5 (620.6 to 741.2) | 518.0 (475.1 to 578.0) | 836.5 (750.2 to 957.4) |
| Schools close | | | | | |
| Before school closure (during lag period: days 1-16) | 37.0 (30.5 to 45.0) | 23.3 (16.1 to 30.6) | 31.8 (23.1 to 43.7) | 32.6 (24.1 to 44.1) | 81.2 (55.5 to 106.8) |
| After lag period (days 17-42) | 214.8 (175.0 to 263.7) | 151.2 (103.8 to 198.5) | 230.8 (165.9 to 321.2) | 222.0 (163.0 to 302.4) | 279.9 (189.4 to 370.2) |
| Difference in incidence during 26 d after lag period | | | | | |
| Between states after school closure and hypothetical states where schools remained open | 423.9 (375.0 to 463.7) | 331.4 (294.2 to 383.3) | 455.6 (405.7 to 526.4) | 303.2 (260.3 to 363.2) | 621.7 (535.4 to 742.6) |
| Between states that closed schools after the lag period and states in the highest quartile | NA | -128.7 (-168.7 to -74.2) | -49.1 (-114.0 to 41.3) | -57.8 (-116.8 to 22.6) | 0 [Reference] |

Abbreviations: COVID-19, coronavirus disease 2019; NA, not applicable.

[a] Adjusted for all model components retained in incidence model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and social vulnerability index; before school closure: stay-at-home or shelter-in-place order, restaurant and bar closure, testing rate per 1000 residents, and urban density; after school closure: testing rate per 1000 residents, stay-at-home or shelter-in-place order, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density).

[b] Used slope from line tangential to the curve at the end of the lag period.

[c] Cumulative incidence at the time of school closure for state is set to the adjusted mean.

[d] State with all characteristics set to the mean value for all covariates retained in the model.

100 000. States that closed schools late (in the highest quartile of cumulative incidence of COVID-19) had the largest absolute reduction in cases (621.7 [95% CI, 535.4 to 742.6] per 100 000). However, states that closed schools earlier (in the lowest quartile) had fewer total cases (−128.7 [95% CI, −168.7 to −74.2] per 100 000) during the period after school closure (Table 3). The absolute difference in COVID-19 incidence assuming continued exponential growth appears in eTable 3 in the Supplement.

### Sensitivity Analyses Around the Lag Period

The point estimates ranged from −61% to −63% for the relative change per week associated with school closure as the lag period varied. The point estimates for the relative change for each quartile varied slightly across the lag period (eTable 4 in the Supplement).

## COVID-19 Mortality

The observed death rates in each state by quartile of cumulative incidence of COVID-19 at the time of school closure appears in Figure 1B. In the unadjusted analyses during the period prior to potential effects of school closure (ie, during the lag period), the overall relative change in mortality per week was 171% (95% CI, 160% to 184%). In the unadjusted analyses, the relative mortality change per week associated with school closure was −64% (95% CI, −67% to −61%). The unadjusted effect size associated with school closure varied by COVID-19 cumulative incidence at the time of school closure, with states in the lowest quartile having the largest associated effect size (Table 2).

In the adjusted analyses during the period prior to potential effects of school closure (ie, during the lag period), COVID-19 mortality increased by 186% (95% CI, 175% to 197%) per week (Table 2). The overall combined composite relative weekly change in mortality after school closure was 2% (95% CI, −8% to 14%; Table 2). This composite change in mortality after school closure is visually depicted in Figure 2. When examining only school closure, it was associated with a relative change per week in COVID-19 mortality of −58% (95% CI, −67% to −46%). This association was greatest in states with the lowest cumulative COVID-19 incidence at the time of school closure (relative change per week of −64% [95% CI, −73% to −52%]). In comparison, states that closed schools later when cumulative COVID-19 incidence was in the highest quartile had the smallest associated relative decline in mortality (−53% [95% CI, −63% to −40%]; Table 2 and Figure 2). The full model with all covariates appears in eTable 5 in the Supplement. The relative change in mortality associated with school closure varied significantly by restaurant and bar closure and urban density.

The absolute effects associated with school closure during the 16-day period after school closure (days 27-42), which were calculated using model estimates with the assumption of linear growth, yielded 19.4 deaths per 100 000 that would have occurred if schools had remained open (**Table 4**). Compared with the 6.8 deaths per 100 000 estimated from the school closure model, the absolute difference associated with school closure was 12.6 (95% CI, 11.8 to 13.6) deaths per 100 000

Table 4. Estimated Absolute Differences in COVID-19 Deaths[a] Between School Closure and Schools Remaining Open Using Linear Projection[b]

| | COVID-19 deaths per 100 000 in average state[c,d] | Estimated absolute difference (95% CI) in deaths per 100 000 by quartile of COVID-19 cumulative incidence at school closure[d] | | | |
|---|---|---|---|---|---|
| | | Lowest | Second lowest | Second highest | Highest |
| Schools remain open (projected) | | | | | |
| Before school closure (during lag period: days 1-26) | 3.2 (2.9 to 3.5) | 2.5 (2.2 to 3.0) | 3.1 (2.6 to 3.7) | 2.6 (2.2 to 3.0) | 5.5 (4.7 to 6.5) |
| After lag period (days 27-42) | 19.4 (18.6 to 20.4) | 19.2 (17.9 to 20.8) | 22.1 (20.5 to 24.1) | 14.6 (13.5 to 15.9) | 22.6 (20.6 to 24.9) |
| Schools close | | | | | |
| Before school closure (during lag period: days 1-26) | 3.2 (2.9 to 3.5) | 2.6 (2.1 to 3.0) | 3.1 (2.6 to 3.7) | 2.6 (2.2 to 3.0) | 5.5 (4.7 to 6.5) |
| After lag period (days 27-42) | 6.8 (5.8 to 7.9) | 6.3 (5.0 to 7.7) | 7.6 (6.1 to 9.4) | 5.6 (4.7 to 6.8) | 7.9 (6.3 to 9.5) |
| Difference in incidence during 16 d after lag period | | | | | |
| Between states after school closure and hypothetical states where schools remained open | 12.6 (11.8 to 13.6) | 12.4 (11.1 to 14.0) | 15.3 (13.7 to 17.3) | 7.8 (6.7 to 9.1) | 15.8 (13.9 to 18.1) |
| Between states that closed schools after the lag period and states in the highest quartile | NA | -1.5 (-2.7 to -0.1) | -0.3 (-1.8 to 1.5) | -2.3 (-3.2 to -1.1) | 0 [Reference] |

Abbreviations: COVID-19, coronavirus disease 2019; NA, not applicable.

[a] Adjusted for all model components retained in mortality model (intercept: percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, and social vulnerability index; before school closure: stay-at-home or shelter-in-place order, prohibition of gatherings with >10 people, restaurant and bar closure, percentage of state's population aged ≤15 years, percentage of state's population aged ≥65 years, number of nursing home residents per 1000 people, and urban density; after school closure: restaurant and bar closure, number of nursing home residents per 1000 people, and urban density).

[b] Used slope from line tangential to the curve at the end of the lag period.

[c] Cumulative incidence at the time of school closure for state is set to the adjusted mean.

[d] State with all characteristics set to the mean value for all covariates retained in the model.

(Table 4). States that closed schools late (in the highest quartile of COVID-19 cumulative incidence) had the largest absolute reduction in deaths (15.8 [95% CI, 13.9 to 18.1] per 100 000). However, states that closed schools earlier (in the lowest quartile) had fewer estimated total deaths (−1.5 [95% CI, −2.7 to −0.1] per 100 000) during the period after school closure (Table 4). The absolute difference in deaths assuming continued exponential growth appears in eTable 3 in the Supplement.

### Sensitivity Analyses Around the Lag Period

The point estimates ranged from −55% to −61% for the relative change associated with school closure as the lag period varied. The point estimates for the relative change for each quartile varied slightly across the lag period (eTable 4 in the Supplement).

## Discussion

Between March 9, 2020, and May 7, 2020, school closure in the US was temporally associated with decreased COVID-19 incidence and mortality. States that closed schools earlier (when the state's cumulative incidence was lower) had the largest relative reduction in overall incidence and mortality.

In March 2020, states enacted multiple nonpharmaceutical interventions, including closing schools, nonessential businesses, and restaurants and bars, and prohibiting large gatherings, to curb SARS-CoV-2 spread and prevent death. Completely isolating the effects of any single nonpharmaceutical intervention is impossible because recommendations for increased handwashing, cleaning, and wearing of masks evolved simultaneously. Measured COVID-19 incidence also was affected by testing availability, which was limited early in the pandemic and varied nationally.

In this study, changes in COVID-19 incidence and mortality associated with school closure were isolated to the extent possible by adjusting for other state-enacted policies and testing rates. In adjusted models, school closure was associated with decreased COVID-19 incidence and deaths. These analyses do not incorporate the risks of school closure on child education and development or from a societal perspective. However, the analyses suggest that school closure may be effective in curbing SARS-CoV-2 spread and preventing deaths during future outbreaks.

These findings complement evolving evidence on the role of children in the transmission of SARS-CoV-2. Studies have documented lower attack rates for children,[28] and children comprise a small proportion of documented infections.[29] Children may be less susceptible to SARS-CoV-2 infection[30]; however, studies have documented viral shedding in asymptomatic children.[31] Recent studies suggest school closure may have only modest effects on COVID-19 deaths.[32-35] School closure in this study was associated with a −62% relative change in COVID-19 incidence per week. A decline of 62% was equivalent to 39% of the projected value with schools open. So, per week, the incidence was estimated to have been 39% of what it would have been had schools remained open. Extrapolating the absolute differences of 423.9 cases and 12.6 deaths per

100 000 to 322.2 million residents nationally suggests that school closure may have been associated with approximately 1.37 million fewer cases of COVID-19 over a 26-day period and 40 600 fewer deaths over a 16-day period; however, these figures do not account for uncertainty in the model assumptions and the resulting estimates.

The analyses presented here suggest that the timing of school closure plays a role in the magnitude of changes associated with school closure. As hypothesized, school closure in states that enacted this intervention early (when the cumulative incidence of COVID-19 was low) had greater associated relative decreases in incidence and mortality. Although these relative differences translate into smaller absolute differences associated with school closure, states that closed schools later (in the highest quartile of COVID-19 cumulative incidence) had more new cases and deaths from COVID-19 during the period after school closure. Thus, this study can inform future decisions about optimal timing for state and local officials to consider school closure to curb SARS-CoV-2 spread in the high likelihood that the pandemic continues.

The mechanism by which school closure could affect COVID-19 spread is not only through disrupting spread by or among children. School closure affects family routines, necessitating alternative childcare and modified work schedules. These changes are evident by the number of teleworkers more than doubling.[36,37] The disruption in everyday life likely influenced how people engaged in group activities, traveled, and conducted business. If the primary effect associated with school closure is related to altered adult behavior, and not children spreading the virus to adults, the primary lag period considered in these analyses should be adjusted. Eliminating the 4 days for a child to adult transmission would result in a COVID-19 incidence lag period of 12 days and a mortality lag period of 22 days. In sensitivity analyses, the effect sizes associated with school closure at these shorter lag periods were similar to the primary analysis effect sizes. The degree to which the associations with school closure relate to decreased spread of SARS-CoV-2 by children or a combination of child and adult factors is unclear. Because school closure was the first nonpharmaceutical intervention in most states, the effects associated with school closure may be larger than if school closure had followed other nonpharmaceutical interventions.

It is unclear how COVID-19 spread would be affected if schools remained open while states enacted other policies to restrict movement. It is possible school-related spread may be mitigated with infection-control interventions recommended by the CDC and the American Academy of Pediatrics, including frequent handwashing, universal mask policies, physical distancing measures, and increased sanitation procedures.[38,39] However, given that school closure also alters adult behavior, decreasing COVID-19 spread within schools may be inadequate as a stand-alone intervention and may require continued alteration of adult interactions.

### Limitations

This study has several limitations. First, many states enacted additional nonpharmaceutical interventions concurrently with or shortly after school closure, making it impossible to fully isolate potential effects of school closure. Some nonpharmaceutical interventions, such as increased handwashing, could not be included due to lack of available data.

Second, analyses were conducted at the state level. The analyses did not account for resident travel leading to viral spread between states. Even though the study modeled state-level policies, some states had more restrictive policies locally (ie, by county). Nevertheless, these analyses are useful to understand the practical implications of state policy in containing spread.

Third, inadequate testing has impeded COVID-19 diagnosis. Testing variability was accounted for with the use of state-level testing rates as a model covariate; however, testing rates do not fully capture a state's testing capability, infrastructure, and strictness of testing guidelines.

Fourth, the completeness and accuracy of the Johns Hopkins University database with respect to COVID-19 incidence and mortality has not been established. This data source aggregates publicly available data and accuracy may vary state to state. As with limitations in testing, inconsistencies in reporting are unavoidable limitations of all COVID-19 US population-based studies.

## Conclusions

Between March 9, 2020, and May 7, 2020, school closure in the US was temporally associated with decreased COVID-19 incidence and mortality; states that closed schools earlier, when cumulative incidence of COVID-19 was low, had the largest relative reduction in incidence and mortality. However, it remains possible that some of the reduction may have been related to other concurrent nonpharmaceutical interventions.

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