The Effect of Reactive School Closure on Community Influenza-Like Illness Counts in the State of Michigan During the 2009 H1N1 Pandemic

Q1 **Brian M. Davis,[1] Howard Markel,[2] Alex Navarro,[2] Eden Wells,[1] Arnold S. Monto,[1] and Allison E. Aiello[3]**

[1]Epidemiology Department, University of Michigan, Ann Arbor; [2]Center for the History of Medicine, University of Michigan, Ann Arbor; and [3]Epidemiology Department, University of North Carolina, Chapel Hill, North Carolina

In sum, 559 Michigan schools were closed as a nonpharmaceutical intervention during the influenza A 2009 (H1N1) pandemic. By linking the proportion of schools closed within a district to state influenza-like illness (ILI) surveillance data, we measured its effect on community levels of ILI. This analysis was centered by the peak week of ILI for each school district, and a negative binomial model compared three levels of school closure: 0%, 1%–50%, and 51%–100% of schools closed from three weeks leading up to ILI peak to four weeks following ILI peak rate. We observed that school closures were reactive, and there was no statistically significant difference between ILI rates over the study period. There was an elevated rate ratio for ILI at 51%–100% closure, and a reduction in the rate ratio at the 1%–50% compared to the 0% closure level. These findings suggest that district level reactive school closures were ineffective.

Keywords. Influenza; influenza-like illness; school closure; nonpharmaceutical interventions.

At the start of the 2009 influenza A (H1N1) pandemic, the Centers for Disease Control and Prevention (CDC) recommended proactive school closures as a nonpharmaceutical intervention (NPI) whenever a confirmed or probable case of 2009 influenza A (H1N1) was identified in a school [1]. On 5 May 2009, the CDC modified its guidelines, emphasizing local decision making and recommending school closures only when high absenteeism interfered with a school's educational mission [2]. Over 3000 schools in the United States closed during the spring and fall waves of the 2009 influenza A (H1N1) pandemic.

We studied retrospective data on 559 school closures in the state of Michigan during the fall wave of the 2009 influenza A (H1N1) pandemic. Most were reactive and occurred late in these school districts' pandemic experience [3]. We hypothesized that late school closures would not result in a significant difference in influenza-like illness (ILI) rates in these communities.

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Q2 Q3 Correspondence: Howard Markel, MD, 102 Observatory St, Rm 5725, Ann Arbor, MI 48109 (howard@umich.edu).

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METHODS

We used data from the Michigan Department of Community Health (MDCH) collected during the fall of 2009. The MDCH proactively recorded information on school closures from 559 public traditional, public charter and private K-12 schools during the fall term in response to 2009 influenza A (H1N1). Several schools issued multiple closures during the period, for a total of 567 separate school closure incidents. This study was considered an activity not regulated by the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board (HUM #00091632).

Influenza-like Illness Outcomes

The primary outcome of interest was the weekly ILI count for each school district. In addition to schools closed, MDCH provided a list of all ILI cases reported from 1 September through 31 December 2009. Of 7000 reports to the Michigan Disease Surveillance System (MDSS) containing zip codes, 1248 had dates for both referral and symptom onset. To more accurately reflect what the unreported onset may have been for the 5752 individuals without onset date, we calculated the median days between referral and onset among the 1248 with complete information. We then subtracted that value from those with only a referral date, by week, to estimate the date of onset. We adjusted our reported onset time to allow for an assessment of how additional epidemiological information over that time period may have changed reporting practices.

To determine the time period for analysis, we calculated a weekly ILI rate for each district by summing the ILI cases per week and dividing them by the total population in each school district. The peak ILI rate was based on two different methods: districts that had 3 or more weeks of ILI data were assigned a peak week based on the maximum rate of ILI per 100 000 persons. Districts with less than 3 weeks of ILI data, or a peak week occurring prior to 10th October, were assigned a peak week value based on their public health region. After accounting for a 1-week lag to assess closure impact on ILI, we set the peak week for each school district as our 0 week and looked at ILI counts 3 weeks preceding and 4 weeks following peak
Q4 ILI rate in our models (See Figure 1).

School Districts

Information about individual schools and districts were accessed electronically from the Michigan Department of Education's Center for Educational Performance and Information (CEPI). During the 2009–2010 academic year, all schools in the CEPI database could be geographically assigned to 551 public school districts. One district contained no open and eligible schools during our study period, and 2 school districts contained population sizes that skewed ILI rates; these were dropped from analysis. The final dataset analyzed contained 548 districts. We considered a school district "closed" if at least one school closed and "open" if no schools in the district closed at any point during the study period. Supplementary Table 1 contains information for each state school district.

Closed Schools

The CEPI database contains information on 10 145 school districts, nonclassroom facilities, nonschool recipients, unique education providers, and public, public charter, and private schools [4]. We limited our analysis to schools only, leaving us with 6469 unique state institutions. We removed from our dataset 2038 schools that were not in session during the fall 2009 semester; 100 schools that encompassed special education, adult education, juvenile detention, and other facilities not under normal closure pressure; 28 schools with no grade information; and 8 online/virtual schools. Of these 4294 remaining schools, 559 reported at least 1 closure during the fall wave of 2009 influenza A (H1N1).

Statewide Geographical Data

We used 2 statewide geographical shape files to assign population size and outcome of ILI counts, and to assess peak ILI rates in the greater community. We used the US 2010 Census, which contained school district information with associated housing density.

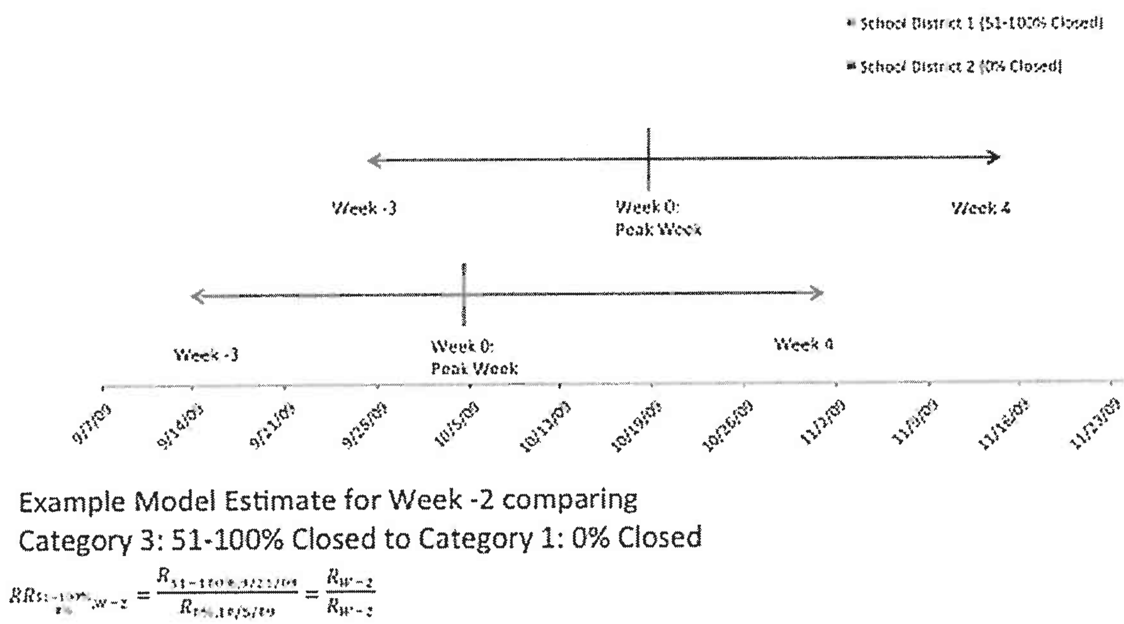

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Figure 1. Illustration of centering of our peak week of influenza-like illness for comparisons, as well as example of our relevant outcome. Q8

Next, a shape file for each of the 988 Zip Code Tabulation Areas (ZCTAs) in Michigan was accessed to delineate population by age; ZCTAs are used to combine census blocks with US Postal Service data and are often coterminous with zip code-defined areas, although boundary differences sometimes occur in rural areas [5]. This allowed us to calculate the proportion of the school-aged population (5–17 years of age) and total population within each ZCTA, and provide a geographic area for our ILI cases.

We then overlaid a statewide shape file (provided by the Geodata Services section of the Michigan Department of Technology, Management, and Budget) containing polygons representing each of the public school districts in Michigan. The shape file represented school districts as of 2011, when 551 school districts covered the state.

These two shape files were read into ArcGIS 10.1 (Redlands, CA) in order to determine which ZCTAs were contained within each school district. An intersect merge of the 2 layers enabled an identification of ZCTAs for each school district that provided the school-aged and total populations. These data were then exported to the statistical software package for additional analysis.

Statistical Methods

School district level data from the CEPI dataset was summarized using SAS 10.1 (Cary, NC). Select data were aggregated across individual school levels into district-wide variables: proportion of students eligible for the National School Lunch Program (NSLP), which we used as a proxy measurement for district socioeconomic level; type of school (public, private, public charter); and eligible grade levels. We derived the main predictor—the proportion of schools closed in a district varying over time—using the total number of schools closed by week over the total number of schools in the district. Due to the asymmetric distribution of our raw data describing the proportion of schools closed in each district, we consolidated this value into 3 levels of closure:

Level 1: 0% of all schools in a district close for a given week;
Level 2: 1% to 50% of all schools in a district closed for a given week;
Level 3: 51% to 100% of schools in a district closed for a given week.

To assess the effect of closure timing, we examined characteristics of individual schools and districts. Grade level and number of days closed were assessed among districts that closed prior to the week of peak infection and districts that closed at or following peak infection, determined by measuring the weeks of closure for each school district and subtracting that week value from the peak week of infection. Differences between categorical and quantitative variables were calculated using χ^2 and t-tests.

The outcome of interest for our analyses was weekly ILI counts per district. We used a log population per district offset to account for differences in the size and population density of the school districts, with a 1-week lag to allow assessment of closure impact. To accommodate the ILI count data and offset while accounting for clustering within school districts over time, we fit a longitudinal model examining changes in the counts of ILI using PROC GENMOD with a negative binomial link statement in SAS 10.1. Negative binomial models are often appropriately used for count data when the variance exceeds the mean, as was the case in our study [6]. The full model was adjusted for additional covariates, including whether the school was public or private, the percentage of NSLP-eligible students, the number of enrolled students, and the density of houses per square mile in the district. We calculated estimates for differences between school districts, comparing level 1 (0% closed), level 2 (1%–50% closed), and level 3 (51%–100% closed). Figure 1 illustrates the time frame and comparison groups used to estimate ILI rate ratios (RR).

RESULTS

We analyzed 559 schools that closed in 548 school districts active during the 2009 academic year; 170 school districts had at

Table 1. Descriptive Information About School Districts With at Least One School Closure Compared to No School Closure During the Fall 2009 Term in the State of Michigan Q11

	Closed Districts N = 170	Open Districts N = 378	*P* Value	
Total number of schools	1434	2882		
School level			.003	
Elementary	841 (58.7)	1695 (58.8)		
Jr. high school	151 (10.5)	329 (11.4)		
Jr. sr. high school	97 (6.8)	156 (5.41)		
Sr. high school	221 (15.4)	536 (18.6)		
K-12	124 (8.7)	166 (5.8)		
School type			.002	
Public school	1057 (73.7)	2186 (75.9)		
Public charter school	79 (5.5)	208 (7.2)		
Private school	298 (20.8)	488 (16.9)		
Average number of ILI cases over study period	5.42	6.33	.06	
Average houses per sq. mile per district	182.9	397.3	<.0001	
Average proportion of population 5–17 per district	0.167	0.174	.0002	
Average total students per district	3056.3	3179.2	.80	
Average FR ratio* per district	0.43	0.42	.45	Q9
Average schools per district	8.44	7.62	.48	
Average closed schools per district	3.28	. . .	. . .	
Overall proportion of closed schools per district	0.64	. . .	. . .	

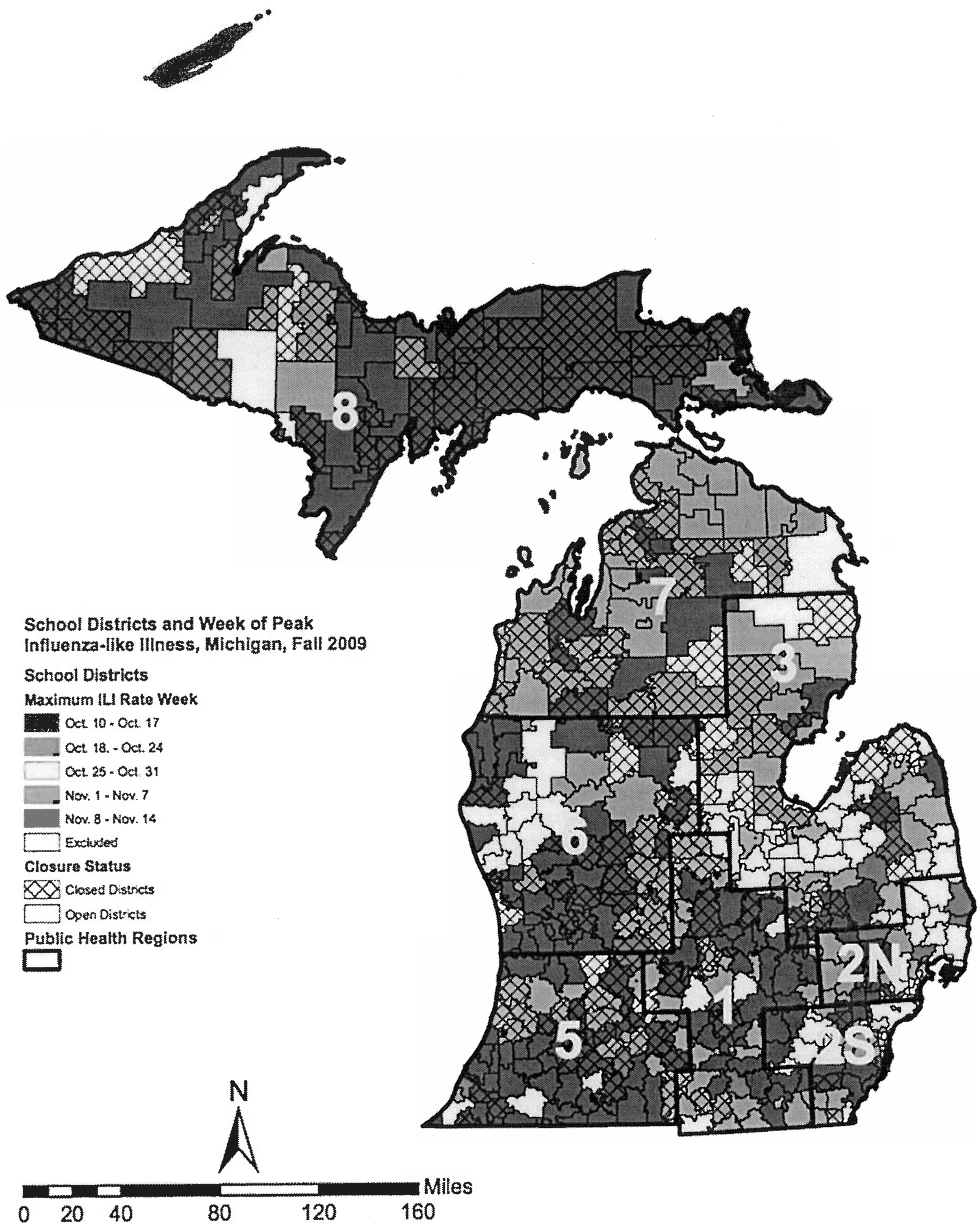

Figure 2. Map of 8 public health regions and 551 school districts in the state of Michigan with district level peak week of infection.

least 1 school that closed, compared to 378 districts in which all schools remained open. These districts accounted for 1434 and 2882 closed and open schools, respectively. Closed districts had a high percentage of Junior/Senior high schools and K-12 180 schools, more private schools, but fewer houses per square mile Q5 (Table 1). We found no statistically significant difference between average total students per district or our proxy socioeconomic measure of NSLP eligibility ratio.

Open districts had a slightly, though not statistically significant, higher average number of cases than closed districts (6.33 vs 5.42, $P = .06$), and a statistically significant higher proportion of the total population that were school-aged (17.4 vs 16.7, $P = .0002$). On average, there were 8.44 schools in closed districts (districts with at least 1 school that closed), compared to 7.62 schools per open district ($P = .48$). Among closed school districts, there was an average of 3.28 closed schools, or 64% of the schools per district. This value was skewed due the large number of school districts (n = 67) where all schools closed (Table 1). A map of open and closed districts, peak week of infection, and public health regions can be found in Figure 2.

In the district-specific analysis, the rate of ILI peaked for public health regions 1, 2S, 3, 5, and 6 during the week of 17 October 2009. Regions 7 and 8 peaked the week of October 24, while region 2N peaked the week of 31 October. Regions 1, 6, and 8 had the highest attack rate (approximately 4 cases per 100 000 persons), with the smallest peak for 2S, with approximately 2 cases per 100 000. A high of 250 Michigan schools closed the week of October 24. An animated graphic of changes in the rate of ILI per school district can be accessed online (Supplementary Figure 1).

The results from our demographic analysis of factors related to school closure are outlined in Table 2. We found no statistically significant differences between closed and open schools with respect to school grade level or school type, though public schools had a higher ILI rate per 100 000 individuals than e private schools or charter schools. Housing density was found to be statistically significant, with a reduction in the number of houses per square mile associated with a higher rate of ILI (rate per 100 000 = 0.88; $P < .0001$).

We observed similar patterns in the time-varying unadjusted model and the model adjusted for grade levels, school type, and housing density, although the fully adjusted model was attenuated toward the null RR or 1.0 (Table 3). No significant differences were observed across any of the weeks in relation to the peak week of infection, comparing level 1 (0% closed), level 2 (1%–50% closed), and level 3 (51%–100% closed). However, level 2 had a lower RR when compared to level 1 or level 3 over the study period. In contrast, level 3 showed higher RR over the study period compared to both level 1 and level 2.

The timing of district and school closures in relation to peak ILI is displayed in Table 4. Of 171 school districts with at least 1 closure, only 19 (11.2%) closed prior to the peak week of infection. This represented a total of 60 (10.8%) of all closed schools, with an average closed duration of 3.74 days (Table 4). Most school closures occurred during either the ILI peak in the corresponding state public health region, or within the 2 weeks

Table 2. Demographic Factors at the District Level Related to School District Closures and Rates of Influenza-like Illness

	Estimated Rate per 100 000 Persons	95% Confidence Interval		*P* Value
Percent of schools closed by week				
School level				
Elementary	1.14	.69	1.87	.61
Jr. high school	0.98	.34	2.83	.97
Jr. sr. high school	1.06	.37	3.06	.91
Sr. high school	1.12	.43	2.91	.81
K-12	1.00	.36	2.82	1.00
School type				
Private school	0.96	.77	1.20	.73
Public charter school	0.96	.91	1.01	.15
Public school	1.30	.32	5.24	.71
Average houses per sq. mile per district	0.88	.86	.91	<.0001
Average proportion of population 5–17 per district	1.15	.62	2.13	.66
Average FR ratio[a] per district	1.08	.95	1.22	.31

[a] FR ratio is the ratio of students receiving free or reduced lunch out of all students in a school.

following peak infection; 363 individual schools (65.1%) closed 1 or 2 weeks following the highest ILI rate.

An assessment of the schools that closed prior to the peak week of ILI compared to those that closed the week of peak infection or after is shown in Table 5. We found no differences between school districts with closure before peak infection and closure during or after peak infection among school level, school type, total number of students enrolled, or NSLP eligibility ratio. We did observe a statistically significant greater number of days closed among schools that closed early compared to schools that closed at or following peak infection (pre-peak closure mean days closed 3.74, peak or post peak closure mean days closed 2.95, $P = .04$).

DISCUSSION

We retrospectively analyzed 559 Michigan schools that closed at least once during the 2009 influenza A (H1N1) fall wave. An analysis of the timing of school closure compared to peak ILI suggests that closure was a reactive decision in 83% of the schools. Based on previous studies, it is likely that the remaining school districts had ILI cases that were not reported through MDSS and that all closures were reactive in nature [3, 7]. We found that schools that closed earlier did so, on average, for a slightly higher number of days than those that closed during the peak week of infection or thereafter (Table 4). This may

Table 3. Adjusted Model Predicting Rates of Influenza-Like Illness based on Proportion of Schools Closed per Week

	Unadjusted				Fully Adjusted			
	Rate Ratio	95% CI		*P* Value	Rate Ratio	95% CI		*P* Value
Peak week -3								
1%–50% closed vs 0%	0.60	.07	5.31	.64	0.75	.08	6.83	.80
51%–100% closed vs 0%	2.19	.13	35.74	.58	1.73	.13	23.82	.68
51%–100% closed vs 1%–50%	3.13	.09	110.61	.53	1.78	.06	57.44	.75
Peak Week -2								
1%–50% closed vs 0%	0.53	.14	2.02	.35	0.60	.16	2.31	.46
51%–100% closed vs 0%	2.15	.33	14.20	.43	1.75	.30	10.31	.54
51%–100% closed vs 1%–50%	4.06	.40	41.17	.24	2.90	.31	26.88	.35
Peak Week -1								
1%–50% closed vs 0%	0.53	.22	1.25	.15	0.59	.24	1.42	.24
51%–100% closed vs 0%	1.85	.54	6.36	.33	1.55	.49	4.95	.46
51%–100% closed vs 1%–50%	3.52	.78	15.86	.10	2.64	.61	11.31	.19
Peak week 0								
1%–50% closed vs 0%	0.59	.31	1.09	.09	0.69	.38	1.28	.24
51%–100% closed vs 0%	1.61	.63	4.09	.32	1.36	.57	3.29	.49
51%–100% closed vs 1%–50%	2.75	.89	8.43	.08	1.97	.67	5.73	.22
Peak week 1								
1%–50% closed vs 0%	0.65	.37	1.14	.13	0.82	.47	1.45	.49
51%–100% closed vs 0%	1.40	.71	2.76	.33	1.20	.62	2.31	.58
51%–100% closed vs 1%–50%	2.14	.89	5.15	.09	1.47	.62	3.46	.38
Peak week 2								
1%–50% closed vs 0%	0.65	.36	1.17	.15	0.80	.43	1.47	.47
51%–100% closed vs 0%	1.21	.74	1.97	.46	1.06	.65	1.74	.81
51%–100% closed vs 1%–50%	1.86	.88	3.95	.11	1.33	.62	2.87	.47
Peak week 3								
1%–50% closed vs 0%	0.58	.15	2.18	.42	0.64	.16	2.60	.54
51%–100% closed vs 0%	1.03	.28	3.83	.96	0.94	.27	3.29	.93
51%–100% closed vs 1%–50%	1.79	.28	11.38	.54	1.47	.23	9.43	.69
Peak Week 4								
1%–50% closed vs 0%	0.46	.03	6.73	.57	0.43	.02	7.64	.56
51%–100% closed vs 0%	0.88	.06	13.21	.92	0.84	.07	10.92	.90
51%–100% closed vs 1%–50%	1.91	.04	85.41	.74	1.98	.04	92.24	.73

* Adjusted for grade level, school type, free and reduced lunch ration, and housing density

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reflect either the severity of illness within the schools that closed early (resulting in a longer duration of school closure), or uncertainty related to district closure guidelines during the fall term.

Our findings suggest that districts with 1%–50% of schools closed had a lower ILI RR than school districts with 0% of schools closed or 51%–100% of schools closed. This could be explained by differing demographics of 1%–50% closed vs open districts (Table 1). School districts with 1%–50% closures may have experienced lower ILI rates than open schools due to (1) differences in underlying population size or density, at-risk populations; or (2), timing of the ILI peak wave.

In contrast, districts with schools closed at the highest level (51%–100%) had the highest ILI rate ratio. Although more ILI cases occurred in open school districts than closed, these also had a higher proportion of school-aged children. ILI rates better address the underlying influence of population; a significant association of lower housing density with higher ILI correlates with findings that less-populated areas of the state were heavily affected (Supplementary Figure 1) and had high rates of reactive school closures. These ILI rates also suggest that the school closures may have been implemented too late to be an effective NPI. Indeed, a recent survey of Michigan school closures during the fall wave of 2009 influenza A (H1N1) found that the most likely reason given for school closure was high absenteeism, suggesting a reactive rather than proactive intervention [3].

Table 4. Average Duration, in Weeks, Between Peak ILI for a Public Health Region Where for Each School District and When School Districts and Schools Were Closed

Weeks Between Max ILI Rate for Region and School Closure	Total Districts Closed	Total Closed Schools	Average Days Closed	Proportion of Total Schools Closed
−3	1	3	4.67	1.00
−2	4	14	6.57	0.77
−1	14	43	4.79	0.63
0	32	96	4.75	0.62
1	73	249	4.45	0.62
2	38	114	4.52	0.53
3	18	31	5.35	0.52
4	7	8	4.75	0.34

Brief reports, modeling, historical epidemiological analyses, and observational studies of seasonal and pandemic influenza events support our findings. A growing number influenza outbreak studies suggest that, although proactive school closures may help slow the course of a pandemic [8–10], reactive or short-term closure show little to no effect [11, 12] on ILI, or reduce illness only in school-aged populations [13, 14].

Due to the nature of the data, there were some limitations to our research. First, there is the probability of underreporting of ILI cases and incomplete MDSS surveillance data. The high sensitivity of ILI definition increases the number of cases identified. However, ILI is an imprecise measure of influenza, and select individuals with symptoms matching the ILI case definition may not be infected with influenza. Further, a majority of the cases were identified through school reporting, and were not medically attended. Second, we were unable to assess the effect of absenteeism in this study. We had limited access to the number of absent students among schools that closed, and no information on schools that remained open, resulting in our inability to control for the number of number of students out of school. Previous studies have shown that absenteeism was an important factor in school closure [3]. Third, our data are limited by a lack of complete information for available zip codes. Fourth, the small number of districts with school closures prior to peak week of infection made it difficult to assess whether any of these closures were truly preemptive or whether early school closures can translate to a reduction in rates of illness in the population. Fifth, the categorization of school districts as "open" vs "closed" is likely too coarse to address actual differences between the schools; however, the designation was chosen to simplify complications related to the time-varying nature of the school closures, and to attempt to determine if there were any nonvarying demographic differences between open and closed districts. Finally, the 2009 pandemic may not be an appropriate context to test the effectiveness of school closures as an NPI; the CDC deemphasized proactive school closures when it became clear that the 2009 influenza A (H1N1) pandemic was less severe than initially feared.

Table 5. Characteristics of Closed Schools Based on Early Closure (Anytime Before Peak Week of Infection) and Reactive Closure (From Peak Week of Infection to Four Weeks Following Peak Week of Infection)

	Pre-Peak Closure	Peak or Post-Peak Closure	*P* Value
Total number of schools	57	501	
School level			.36
Elementary	28	277	
Jr. high school	8	54	
Jr. sr. high school	8	42	
Sr. high school	11	87	
K-12	2	41	
School type			.60
Public school	51	50	
Public school academy	3	29	
Private School	3	422	
Average total students	334.40	346.70	.71
Average free and reduce lunch ratio	0.48	0.48	.93
Average days closed	3.74	2.95	.04

Still, our study is the first to link ILI surveillance data with reports of school closures captured in real time across an entire state. Our findings suggest that school closures employed in Michigan during the fall wave of 2009 influenza A (H1N1) pandemic had little effect on circulating levels of ILI. Our findings also demonstrate that reactive school closures did not significantly reduce the rate of illness compared to schools that remained open. We observed a small number of districts that implemented closure prior to peak infection, as measured by surveillance data, also fit this trend. Whether this was a result of undetected circulating disease or late reporting is unknown; more intensive disease surveillance in the community setting is required. Nevertheless, this study combined information at the school district level with ILI surveillance data to provide a quantitative analysis of the effect of reactive school closure during fall of 2009. Further studies that explore the impact of school closure as an NPI on ILI are recommended.

Supplementary Data

Supplementary materials are available at Clinical Infectious Diseases online (http://cid.oxfordjournals.org). Supplementary materials consist of data provided by the author that are published to benefit the reader. The posted materials are not copyedited. The contents of all supplementary data are the sole responsibility of the authors. Questions or messages regarding errors should be addressed to the author. Q6

Notes

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All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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Online Summary text

We examined the association between school closures and community level influenza-like illness (ILI) in Michigan during the 2009 H1N1 influenza A pandemic. We found that most school closures were reactive and had no effect on community ILI.