Department
of Health

Impact of School Closures on an Influenza Pandemic

Scientific Evidence Base Review

May 2014

Title: Impact of School Closures on an Influenza Pandemic Scientific Evidence Base Review

Author: PH-HPER-ID&BP 10200

Commissioned by the Department of Health and produced by Public Health England

Document Purpose: A review of the scientific evidence base of the impact of school closures on an influenza pandemic

Publication date: 05/2014

Target audience: Supporting Documents for UK Influenza Pandemic Preparedness Strategy

Contact details:

Elizabeth Paterson
Richmond House
79 Whitehall
LONDON
SW1A 2NS
Email: Elizabeth.paterson@dh.gsi.gov.uk

Published to gov.uk, in PDF format only.

www.gov.uk/dh

May 2014

Contents

Document information

Document date: March 2013

Final Version

Document sponsor: Influenza and Respiratory Virus Delivery Board, Public Health England

Authorised by: Professor John Watson

Authors and affiliations:

Charlotte Jackson,
London School of Hygiene & Tropical Medicine
Public Health England

Punam Mangtani,
London School of Hygiene & Tropical Medicine

Emilia Vynnycky,
Public Health England
London School of Hygiene & Tropical Medicine

Acknowledgements
Special thanks to Jeremy Hawker (Field Epidemiology Services, Public Health England) Nadia Inglis (HPA), Angus Nicoll (ECDC), Babatunde Olowokure (formerly regional epidemiologist with the Health Protection Agency) and two anonymous reviewers for helpful comments on the initial review conducted in August 2010. We also thank staff at the LSHTM library for assistance in locating papers. This update was peer reviewed by the Scientific Pandemic Influenza Advisory Committee, March 2013

Funding

Supported by internal funding of the Health Protection Agency and the Department of Health. Charlotte Jackson was supported by an NIHR Research Training Fellowship for the initial review

Declarations of interest

Charlotte Jackson, Punam Mangtani and Emilia Vynnycky have been involved in an NIHR funded study of the effects of school closures on contact patterns and transmission of infection.

Executive Summary

Background
School closure has been recommended as a potential component of a mitigation strategy during an influenza pandemic, and schools were closed in the UK and elsewhere during the 2009 pandemic. This report aims to inform the development of options for policy in influenza pandemics by collating and updating the evidence base concerning the effects of school closure on influenza transmission.

Objectives
This review summarises literature published up to 31 October 2012 investigating school closures as a mitigation strategy for pandemic influenza based on:

- Epidemiological studies of the effects of routine and reactive school closures on the course of outbreaks of seasonal or pandemic influenza
- Mathematical modelling studies of the effects of school closure on an influenza pandemic

Methods
Separate literature searches were carried out to identify 1) epidemiological and 2) mathematical modelling studies of the effects of school closures on the course of outbreaks of seasonal and pandemic influenza. Results from searches of Medline, Embase and Pubmed were supplemented with hand searches of key journals and the reference lists of identified articles.

Results
100 epidemiological and 45 modelling studies, which presented relevant information, were identified. Of the epidemiological studies, 27 referred to seasonal influenza outbreaks and 77 to pandemic influenza (4 included data on both seasonal and pandemic influenza). Of the 77 studies of pandemic influenza, 69 referred to the 2009 pandemic, 1 to the 1968 pandemic and 7 to the 1918 pandemic. Many of the studies were descriptive outbreak reports which did not aim specifically to assess the effects of school closure on the course of the epidemic.

Interpretation of many of these studies was complicated by factors such as difficulties in separating the effects of school closures from the natural transmission dynamics of influenza, and the concurrent use of other interventions. However, other studies included rigorous analysis to take account of the natural transmission dynamics of influenza, or compared outbreaks between communities in which schools did and did not close. Of these studies, several provided evidence that school closures can reduce transmission, although in others no effect was seen. This may have been because closure occurred late in the outbreaks in these settings. There was little evidence from the published epidemiological studies which could be used to judge the most appropriate threshold at which to close schools.

The modelling studies varied in their assumptions (e.g. regarding population contact patterns and how these are affected by school closures) and consequently predicted a range of possible outcomes resulting from school closure during an influenza pandemic. School closure was, however, consistently predicted to lead to a greater reduction in the peak incidence of infection than in the cumulative attack rate. Only under extreme assumptions, whereby school closure greatly increased children's contact rates (e.g. doubling the number of contacts which they made outside of school), was closing schools predicted to result in increases in the peak and cumulative attack rates.

Discussion

The epidemiological evidence suggests that school closures can influence transmission of pandemic influenza, although this is dependent on timely implementation. The apparent lack of an effect on morbidity in some studies may be due to the fact that schools were often closed relatively late in the respective outbreaks.

Modelling studies usually predict that school closure will result in greater reductions in peak than in cumulative attack rates. Reductions in peak attack rates can help to reduce pressure on limited healthcare services such as intensive care. The variability in the assumptions underlying these models, for example regarding the effects of school closures on contact patterns, is often due to a lack of suitable data. This makes predictions only indicative rather than necessarily accurate assessments of the size of the effects on the course of an epidemic. Modelling studies suggest that school closures are likely to have the greatest effect if the virus has low transmissibility and if age-specific attack rates are higher in children than in adults. They also suggest that early closures are associated with the greatest reductions in the peak attack rate but that this is also dependent on the duration of closure.

The published evidence does not allow an estimate of the optimum timing or duration of school closure to be made. The relative benefits of closing individual schools compared to more widespread local or national closures have also been explored relatively little in the published literature. The generalisability of results from specific outbreaks to a future pandemic is unclear. For example, contact patterns may differ between routine and reactive closures, and individuals' behaviour will depend on the perceived severity of infection. School closure also has important social and economic implications which are not considered in this review.

Conclusions and Recommendations

There is currently insufficient evidence to recommend a particular school closure policy (e.g. proactive or reactive) over another. School closure may form a useful component of a mitigation strategy during pandemic influenza, but the timing and duration of closure needed to produce an effect is unclear. Policy should be responsive to the features of a new pandemic virus. For example, if transmission occurs mainly in schools (as during the 2009 pandemic), there is stronger justification for school closure than in the situation where much transmission occurs in adults.

In the early stages of a pandemic a precautionary approach (i.e. closing schools in the absence of strong evidence that this will reduce transmission) may be considered, particularly if the virus is believed to be highly pathogenic. School closure should be accompanied by advice that children should avoid meeting in large groups.

The benefit of school closure in reducing clinically important outcomes needs to be balanced against secondary adverse effects which may not affect all sections of society equally. For example, such adverse effects may be particularly prominent where free school meals are an important source of nutrition or where parents are unable to take time off work or work from home.

Background

During the early stages of the 2009 H1N1 influenza pandemic, several countries closed schools in attempts to slow transmission. This intervention aims to reduce and delay the peak of the epidemic, reducing surges in demand for healthcare and allowing more time for vaccine development. Closures may be either pro-active (occurring before transmission has become established in the school) or reactive (occurring in response to an outbreak within the school) [1]. In the UK, the response to school-associated outbreaks during the first few months of the pandemic included reactive closure of individual schools, if appropriate, (based on a risk assessment for that particular school) together with other interventions such as antiviral prophylaxis and advice that ill individuals should isolate themselves.

Children play an important role in the transmission of influenza and interventions targeted at children have been successful in reducing transmission. For example, vaccination of schoolchildren in Japan against seasonal influenza appeared to reduce mortality (from all causes and from pneumonia and influenza specifically) in the general population [2]. In contrast to vaccination, the aim of school closure is to reduce contact between children and hence reduce the rate of transmission between them and potentially to the wider population (e.g. their household and community contacts).

Whilst the World Health Organization does not specifically either recommend or discourage school closures during an influenza pandemic [3], it has recommended that school closures be considered as a component of a mitigation strategy [4]. However, there has been uncertainty about the effects of school closures on transmission [5]. A recent review of the epidemiological evidence concluded that school closures may have some effect, but that this will depend on the characteristics of the pandemic (e.g. the effects may be greater if age-specific attack rates are higher in children than in adults) and should be balanced against the significant social and economic consequences of the intervention [1]. A WHO consultation in May 2009, involving representatives of six countries, reported that early school closures during the 2009 influenza pandemic had been effective in reducing transmission within schools, although community transmission may not have been affected [6]. Potential adverse secondary effects of school closure, such as work absenteeism and effects on children's education and wellbeing, are also considered in a recent WHO report [3].

This review assesses the published literature on the impact of school closures using evidence from two sources. Firstly, epidemiological studies of the effects of school closures on the incidence and transmission of seasonal and pandemic influenza are reviewed. Mathematical modelling studies predicting the effects of school closures on influenza outbreaks are then also reviewed.

Review questions

Literature searches were developed based on the following individual questions:

How have school closures affected the course of previous influenza epidemics and pandemics?
What do modelling studies suggest about the effects of reactive school closures on influenza epidemics on cumulative and peak attack rates and the duration of the epidemic?

Table 1 summarises these questions in terms of the population, intervention, comparison and outcomes considered for epidemiological and modelling studies).

Table 1: Summary of the review questions

	Epidemiological studies	**Modelling studies**
Population	Any population	Any simulated population
Intervention	School closure (planned or unplanned) during influenza outbreak	School closure (pre-emptive or following identification of case(s))
Comparison	Internal comparison of data before and after closure, or comparison with school(s) which did not shut	Modelled epidemic in the absence of school closure
Outcome	One or more of: clinical or laboratory-confirmed influenza infection, hospitalisation or death, estimate of effective reproduction number, estimate of effect of closure on contact patterns	One or more of: peak incidence, cumulative attack rate, time to epidemic peak, duration of epidemic, effective reproduction number

Methods

Identification of studies

Medline and Embase were searched in December 2012, separately for epidemiological and modelling studies (the full search strategies used in Medline are provided in Appendices 1 and 2; similar search terms were used in Embase). No date limits were applied. To allow for delays in papers being listed in Medline, a broad search of Pubmed (for the words "influenza" and "school") was also carried out, covering publication dates from 1 August to

31 October 2012. No language limits were applied, although in practice we did not translate papers in languages other than English.

Relevant papers from the reference lists of the retrieved articles were also identified. Issues of *Eurosurveillance* (from 23 April 2009 to 25 October 2012), *Morbidity and Mortality Weekly Report* (from 24 April 2009 to 26 October 2012) and *Emerging Infectious Diseases* (from April 2009 to October 2012) were hand searched for reports of outbreaks during which schools were closed, and for modelling studies of school closures. Search results were also supplemented with papers from the reviewers' collections. All papers identified from these sources were subject to the same inclusion criteria as those identified through the electronic database searches.

Study selection

Epidemiological studies were included in this review if they contained information on the course of one or more influenza outbreaks during which schools were closed (with or without other interventions), irrespective of whether assessment of the effects of school closure was the primary objective of the study. Descriptive, statistical and transmission modelling analyses were all included provided that they were based on real epidemic or pandemic incidence data. If papers presented several measures of influenza activity, the most specific data were extracted (e.g. data on laboratory-confirmed influenza were extracted in preference to all-cause school absenteeism).

Modelling studies were included if they modelled school closures during an influenza outbreak and allowed comparison of baseline simulations with no intervention (or a specified intervention) to simulations in which schools were closed. Models which analysed only a generic form of "social distancing" were excluded.

The initial screening of abstracts (and full text where necessary) was carried out by a single reviewer; a second reviewer assessed any paper whose usefulness or findings were unclear to the first reviewer.

Data extraction

Table 2 summarises the information extracted from the epidemiological and modelling studies which were identified as being eligible for inclusion in the review.

Table 2: Information extracted from eligible studies

Epidemiological studies	Modelling studies
Study design	Type of model
Study population / setting	Population structure and contact rates
Nature of school closure (e.g. school holiday, response to outbreak)	Infection parameter values
Duration of closure and number of schools closed	Threshold for closing schools and duration of closure
Timing of closure in relation to influenza circulation	Assumed effects of school closure on contact patterns
Outcome measure(s) examined (e.g. clinical ILI, virologically confirmed influenza)	Predicted effect on peak incidence of infection
Association between school closure and	Predicted effect on cumulative attack rate

outcome	
	Predicted effect on time to peak of epidemic
	Predicted effect on duration of epidemic

Some of the identified modelling studies presented many estimates of the predicted effects of school closure on measures such as the cumulative attack rate, corresponding to different sets of assumptions (including those about the basic reproduction number and the effects of school closures on contact patterns). Where possible in these cases, to illustrate the range of estimates, the most extreme values derived for each value of viral transmissibility were extracted and presented along with the estimate derived from the main analysis.

Quality assessment

Checklists were developed by the authors to assess the usefulness of the epidemiological and modelling studies (Appendices 3 and 4). These were used as prompts to assess the ability of each study to answer the question of whether school closures affect influenza transmission, i.e. the relevance of each study to this review, rather than to formally assess or score study quality. These checklists were not used as inclusion or exclusion criteria. Instead, key issues were considered when reporting the results of the included studies, in particular whether school closure preceded any reductions in incidence or transmission, whether any such reductions appeared greater than would be expected taking into account the natural transmission dynamics, whether any apparent effects were reversed when schools reopened, and whether data from communities in which schools did not close were available for comparison.

Data synthesis

Given the heterogeneity in the design and results of both the epidemiological and modelling studies identified, meta-analysis was not undertaken; the results are instead critically assessed for robustness and consistency and a qualitative assessment of the likely effects of school closures is made.

Results: Epidemiological studies

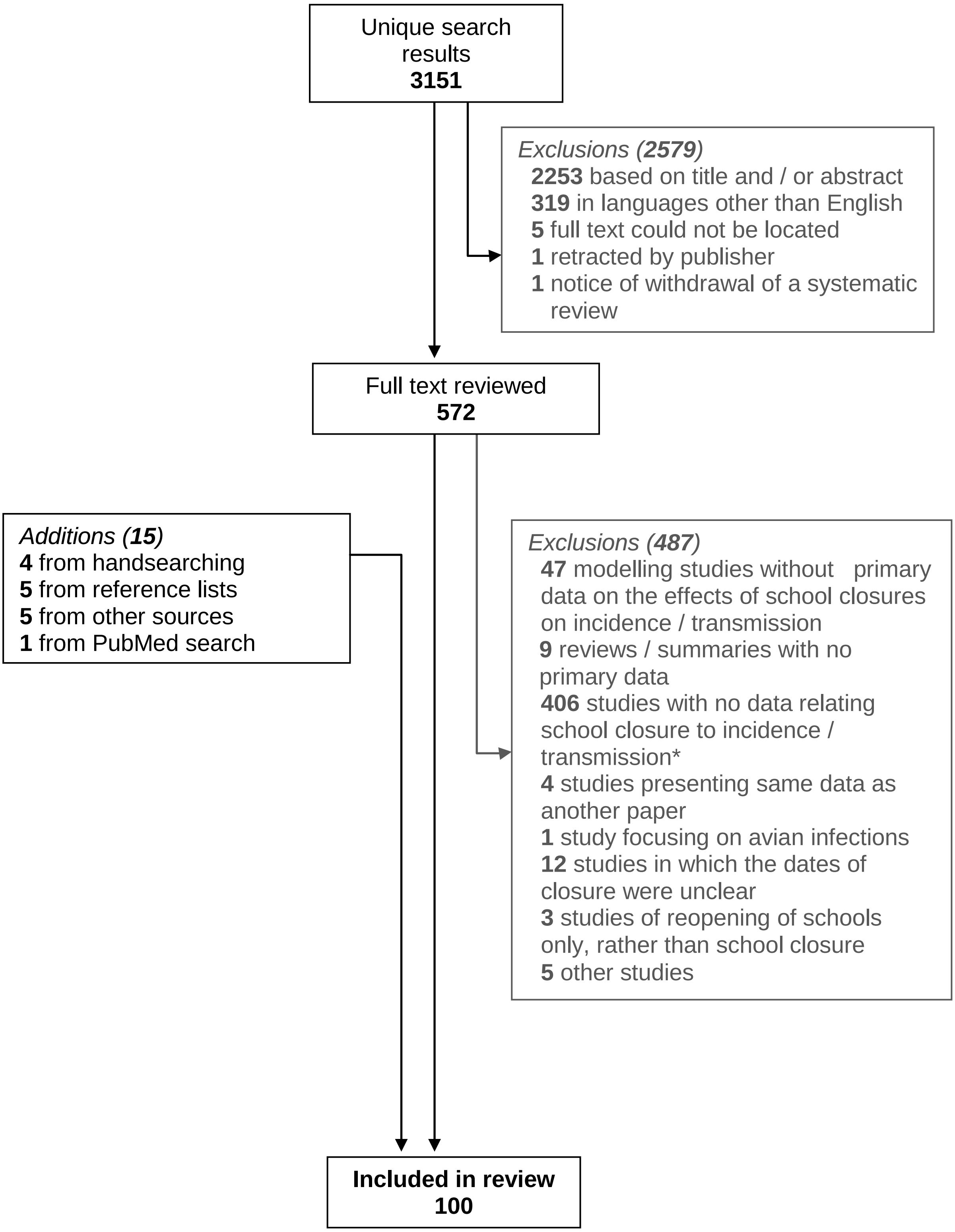
Overview of datasets

Figure 1 shows the numbers of papers identified in the search for epidemiological studies (the search strategy is given in Appendix 1). A total of 3151 papers were identified by searching Medline and Embase, of which 572 were reviewed in full. 85 studies identified through Medline and Embase were included in the review, as well as 15 additional papers (5 from reference lists of the retrieved articles, 4 from handsearching, 1 from the supplementary search of PubMed and 5 from other sources). A total of 100 papers with relevant epidemiological information were thus included in the review.

Appendices 5 and 6 summarise the 27 and 77 studies which contain information on this topic for seasonal and pandemic influenza, respectively (of which 4 studies reported on both pandemic and seasonal influenza). These studies were conducted in a variety of settings in Europe, Asia, Australasia, Africa, and North and South America. Of the studies which presented data from a pandemic, 69 referred to the 2009 pandemic, 1 to the 1968 pandemic and 7 to the 1918 pandemic (none were obtained for the 1957 pandemic).

The studies utilised a variety of designs, some of which were specifically aimed at evaluating the effects of school closures (e.g. [7-26]). Other common study designs were outbreak reports and investigations which included dates of reactive school closures or holidays (e.g. [27-37]), mathematical modelling studies which included real incidence data (e.g. [22, 38, 39]) and evaluations of the use of specific data sources such as school absenteeism in influenza surveillance (e.g. [40, 41]).

Figure 1: Identification of epidemiological studies of the effects of school closure on influenza outbreaks



* Includes outbreaks in which schools did not close and for which it is not stated whether or not schools closed

Effects on incidence

Epidemic curves, where available, are provided in Appendices 7 and 8 for seasonal and pandemic influenza, respectively. In many of the studies, school closure was followed by a reduction in incidence, either in children specifically or in the general population. In contrast, a few showed increases in incidence during closure (e.g. in Abu Dhabi [31]), or found higher mortality rates in cities which closed schools than in those which did not (in Connecticut in 1918) [42].

These associations must be interpreted cautiously. The effects of school closures will depend on the timing of closure in relation to the progress of the epidemic in the population. For example, in several of the studies described in Appendices 5 and 6, closure occurred close to or after the peak of the epidemic [11, 12, 20, 24, 28-30, 36-38, 43-59]. In these circumstances, it is unclear whether subsequent declines in incidence were due to the closures, or a result of the underlying transmission dynamics of influenza and the depletion of susceptible individuals (as noted by some authors, e.g. [24, 37, 47]), or a combination of the two. Furthermore, as noted in a study of the 1918 pandemic in Connecticut, reverse causality may occur when comparing rates in cities which closed schools to those in cities which did not, if closure was a response to a particularly severe local outbreak [42].

However, some studies included concurrent comparison groups and therefore add stronger support for a role of the intervention in reducing incidence. These studies are discussed below.

Three US studies found evidence of an effect of school closure on the incidence of influenza-like illness (ILI) or acute respiratory infection (ARI). One compared self-reported ARI incidence in two districts of Dallas, one of which closed schools whilst the other did not. For each district, the rate difference (RD) comparing the rate of ARI during the one-week school closure to that during the preceding period (~2.5 weeks) was calculated [16]. The “difference in differences” (DID) was calculated as the absolute difference between the two RDs. The DID was -0.47 percentage points (for all ages), comparing the week of closure to the preceding period ($p = 0.046$), with no evidence of a difference between the districts in the RDs comparing the periods during and after school closure (DID = 0.05 percentage points, $p = 0.819$) [16]. The relative increase in the reported incidence of ARI was also smaller in the district where schools closed (from 0.6% before closure to 1.2% during closure, a two-fold increase) than in the comparison district (0.4% to 1.5%, a 3.75-fold increase).

A second US study compared the daily numbers of students reporting to school medical rooms with ILI in schools which did and did not close. All of the schools met the criteria set out by the New York City Department of Health and Mental Hygiene for considering closure: ≥5 students on any one day, and subsequently ≥2.0% (on one day) or ≥1.0% (on two consecutive days) of students, reporting to the school medical room with ILI [17]. Using a negative binomial regression model, the authors estimated that the number of cases on days following days of closure was approximately half of that expected if schools had not closed. Over the full epidemic period, this was estimated to result in a 7% reduction in the total number of cases; the authors note that a larger reduction in case numbers would likely have been seen if schools had closed earlier (case numbers did not increase substantially after meeting the criteria in any of the participating schools [17].

In a third US ecological analysis using data from 21 areas (cities and states), the mean percentage of emergency department and outpatient visits due to ILI was 3.5% where schools were open and 2% where they were closed ($p<0.01$) [15]. This study did not however take account of the natural transmission dynamics of influenza.

An additional study from China estimated that the incidence of suspected and confirmed pandemic H1N1 cases reported to the China Information System for Disease Control and Prevention was 36.4% (95% CI 35.5 – 37.1%) lower during the summer holiday and public holidays, using Poisson regression [60]. This estimate was adjusted for temperature, relative humidity, precipitation, the proportion of school-aged children in the population, population density and density of medical facilities. The analysis appears to include a substantial period of time before the epidemic had taken off (which happened after the summer holiday), although it is unclear how much of this early period coincided with the holiday and therefore how this might affect the estimate[60].

However, other studies which also used rigorous analytical methods found no evidence of an association between school closure and influenza incidence. In King County, Washington in 2007, 205 schools cancelled their midterm break to compensate for missed days earlier in the year whilst 265 schools took this break as normal[11]. There was no evidence of a difference in absenteeism following the break, but the authors noted that closure occurred late in the outbreak. An ecological study of seasonal influenza in Brazil using data from 2001-2008 also found no evidence of an effect of the school term on incidence of laboratory-confirmed influenza but did report some evidence of associations with meteorological variables[18]. It has been suggested that, in areas such as Brazil with diverse climates and relatively limited population mixing, environmental factors may be more important than changes in population contact patterns in influencing influenza transmission[61].

Age-specific effects of school closure

Most available age-specific data suggested that any benefits associated with school closure were greatest amongst school-aged children [7-10, 13, 19-21, 26, 53, 58, 62-67]. In New Zealand during the 2009 pandemic, the ratio of the proportion of all confirmed cases that were in 5-19 year olds to the proportion of the population which was aged 5-19 (described by the authors as the "age-standardised proportion" of cases in children aged 5-19) fell during the winter holiday and increased when schools reopened [66]. Similar relationships between school closure and the ratio of the number of H1N1 infections in 5-20 year-olds to that in other age groups were reported for Mexico [21] and Peru [20]. During the 1967-68 influenza season in Great Britain, GP consultation rates for ILI amongst 5-14 year-olds declined during the Christmas holiday and increased when schools reopened; this effect was less clear in other age groups [65].

Winter holidays in Israel were associated with a reduction in the ratio between the number of clinic visits for influenza and those for non-respiratory complaints, in 6-12 year-olds, in three of five seasonal influenza periods studied [9]. In one season, this ratio was also reduced in adults, and in another it was reduced for adults not living with 6-12 year-olds. When a two-week teachers' strike coincided with an influenza outbreak in January 2000, closing 80% of elementary schools nationwide, this ratio decreased by 15% for 6-12 year-olds (95% CI 6-23%), but not for older individuals. As the authors note, children comprise a high proportion (34%) of the Israeli population, which may contribute to any apparent benefit of closing schools in Israel [8].

Similar data from four influenza seasons in Arizona are less consistent than those from the Israeli study, partly because school closure rarely coincided with elevated influenza activity [26]. During all four seasons, rates of laboratory-confirmed influenza in school-aged children were similar during the two-week winter holiday and the preceding two weeks. In two seasons this rate increased in the two weeks after schools reopened; in one other season, it was significantly lower on reopening than during closure[26]. In comparison, rates in adults and pre-school-aged children increased successively (though not always significantly) across the three two-week periods in three of the seasons[26].

Four studies which fitted transmission models to surveillance data concluded that school closures mainly benefit children [7, 10, 13, 19]. Analyses of French seasonal ILI data [7], ILI data from London during the 2009 pandemic [19] and laboratory-confirmed pandemic H1N1 in Alberta, Canada [10] estimated that school holidays did not affect adults' contact patterns; similarly, reductions in transmission following school closures in Hong Kong in 2009 occurred primarily amongst children [13].

However, two studies of the 2009 pandemic suggested that school closure affected incidence in adults as well as children. One of these studies estimated the age-specific number of ILI cases due to pandemic H1N1 in England; estimated case numbers in most age groups decreased during the summer holiday and increased when schools reopened (this pattern is least clear in the <1 and ≥65 year age groups, in which estimated case numbers were smallest) [67]. In Vojvodina, Serbia, incidence decreased amongst 5-14 and 15-64 year-olds during a one-week school closure[35].

The study from Dallas (discussed above) found the strongest evidence of an effect of reactive school closure amongst individuals aged 19 years and over (compared to children aged 0-5 and 6-18 years)[16]. The DID in this oldest age group was the same magnitude (-0.56 percentage points) as that for 6-18 year olds, but with a lower p value (0.030), despite a similar number of participants in the two age groups. In addition, the estimated relative reduction in ARI rates during school closure was greatest in individuals aged ≥19 years (74%, compared to 39% and 36% in individuals aged 6-18 and 0-5 years, respectively) [16].

Effects on contact patterns

Several papers have used modelling techniques to estimate how population contact rates were changed by school closures, by fitting transmission models to influenza (or ILI) incidence, hospitalisation or mortality data in order to estimate effective contact rates before and during school closure [7, 10, 13, 19, 21, 22, 53, 68-70].

In US cities during the 1918 pandemic, changes in the observed numbers of deaths were explained by a reduction in social contacts arising from both formal interventions (including school closure) and spontaneous social distancing [70]. In Sydney in 1918, such interventions and spontaneous distancing were estimated to have reduced contact rates by up to 38% [69].

Based on influenza incidence data collected during the 2009 pandemic in Mexico City, school closure in conjunction with other social distancing measures was estimated to reduce the population contact rate by 23% [68]. A subsequent analysis of national data from Mexico estimated that the contact rate was reduced by 30% during the intervention period [21]. The rate of effective contact amongst school-aged children was reduced by 70% in Hong Kong during this pandemic [13]. In Alberta, Canada, school holidays during the 2009 pandemic were estimated to reduce contact between children by 86% (95% CI 70-100%) but not to affect contacts of other age groups [10]. Similarly, for seasonal influenza in France (1985-2006), school holiday closures have been estimated to reduce transmission amongst children by 24% (range 20-29%), without affecting transmission to or from adults. The authors quantified this reduction using a statistic which they referred to as the "relative prediction error," and they defined as the percentage difference between the observed incidence during the holidays and the incidence predicted using a model, given the epidemic observed until then [7].

During the 2009 pandemic in London, contact amongst 5-14 year-olds was reduced by an estimated 72% during the six-week summer holiday and by 48% during one-week half term holidays [19]. A modelling study which presented UK incidence data found that the two-wave pattern seen during the 2009 pandemic were consistent with differences in self-reported changes in contact patterns during school holidays compared to term time [22].

Effects on transmission dynamics

Several papers [12, 24, 66, 68] examined the data by estimating daily values of the effective reproduction number (R_n, the average number of secondary infectious individuals generated by a single infectious person in a given population, in which some individuals may already be immune). In Hong Kong in 2008, schools were closed following three seasonal influenza-related paediatric deaths. Subsequent analyses suggested that the effective reproduction number was already below 1 (the threshold value for epidemic spread) when schools were closed, and that it did not appear to be substantially affected by the closures, perhaps due to their introduction late in the epidemic [12]. Analysis of an outbreak in the USA detected no clear effect of school closure on transmission, which was also attributed to the late timing of closure [53]. Similarly, in Mexico during the 2009 pandemic, the effective reproduction number was declining before schools were closed and it is unclear whether closure influenced the rate of decline [21, 68]. In New Zealand, R_n was also declining before schools closed during the 2009 pandemic, but increased briefly (although not substantially) when schools reopened[66].

A further study from Hong Kong during the 2009 pandemic [13] estimated the reproduction number before school closure, during closure of all schools except unaffected secondary schools, and during school holidays which followed the reactive closures. It found successive reductions in the effective reproduction number across these three periods (from 1.7 to 1.5 to 1.1). Similarly, in China, R_n was estimated as 1.25, 0.79 and 1.23 before, during and after a national holiday [25].

Detailed analysis [24] of a pandemic outbreak at a London school [28] reconstructed likely chains of transmission and estimated reproduction numbers by day of symptom onset. The average reproduction number for cases with symptom onset before school closure (but after detection of the outbreak) was 1.33 (95% CI 1.11 – 1.56) compared to 0.43 (95% CI 0.35 – 0.52) during closure. The authors note that this apparent decrease reflects depletion of susceptible individuals as well as any effect of school closure, and suggest that this reduction might represent an upper bound for the effects of school closure on the reproduction number [24].

Modelling analyses of the spatiotemporal spread of pandemic H1N1 in Europe in 2009 were able to reproduce observed incidence patterns only when contact rates were allowed to change specifically during each country's school holidays (holidays were assumed to eliminate transmission in schools and increase community transmission by a factor of 1.4) [71]. In all countries, holidays were estimated to delay the peak compared to a hypothetical situation without school closure. In contrast, regression analysis of estimates of R_n in 12 European countries found no evidence of an effect of school holidays on transmission in the nine countries in which school holidays coincided with the study period (defined for each country as the period between the occurrence of the first case and the discontinuation of testing of the majority of suspected cases) [23]. The authors proposed that this apparent lack of effect might result from changes in reporting, stochastic effects early in the outbreaks, and the fact that in some countries (including England), school holidays did not occur during the study period.

Reversibility of effects

Support for a causal relationship between school closure and reduction in incidence is strengthened if incidence increases again, or if the rate of decline or increase changes when schools are reopened. In some of the studies this cannot be reliably assessed as the data cover only a short period after reopening or the outbreak had already finished. However, in other settings there is evidence of reversibility of the apparent effect of school closures during both pandemic and seasonal outbreaks.

For example, during the 2009 pandemic in England, the estimated weekly number of infections declined during the school summer holiday; a second wave occurred when schools reopened [19, 22, 67, 72]. Similar reversibility appeared in ILI consultation rates in Vojvodina, Serbia, in 2009 [35]. Datasets from the 2009 pandemic in Mexico [21, 68, 73] and Israel [74] also suggested an increase in incidence after schools reopened, as did estimates of R_n (and the underlying incidence data) from China [25]. In New Zealand, there was a slight increase in GP consultation rates for 5-14 year olds when schools reopened [63]. This effect did not seem to appear in any of the other indicators of influenza activity in New Zealand (see Appendix 6), which may reflect greater sensitivity of the GP surveillance system compared to the other surveillance systems, or that the effect of the school holiday on transmission was small and / or confined to schoolchildren.

Analyses of public health interventions during the 1918 pandemic found that none of the cities studied experienced a second wave of infection whilst public health measures, such as social distancing, were in place [70, 75], although second waves did occur after these interventions were discontinued.

For seasonal influenza, during the 1999-2000 influenza season in Japan, the increase in incidence appeared to slow during the two-week winter holiday and accelerated when schools reopened [34]. In January 2000, a nationwide teachers' strike resulted in the closure of 80% of elementary schools in Israel for two weeks, coinciding with an influenza outbreak. An analysis of data on medically attended acute respiratory illness from Israel during this time [8] showed reductions in incidence of 42% and 27% during the closure fortnight and the following two weeks, respectively, compared to the two weeks preceding the closure.

Differences between school closure strategies

Some papers reported on outbreaks in which individual affected schools were closed, whilst others referred to wider (e.g. national) school closures. During the 2009 pandemic, individual reactive school closures occurred in settings including the UK [28, 29, 48, 49, 76], China [77], France [50], Australia [43] and the US [17, 37, 52]. Reactive and / or pro-active closures affecting whole cities, prefectures or countries were implemented in Mexico [68, 73], Japan [30, 51, 78, 79], Hong Kong [13] and Peru [80]. Closure policies in these studies typically appeared not to involve a formally defined threshold for closure; rather, schools tended to be closed as soon as an outbreak was detected or widespread transmission became apparent.

Under both local and national closure strategies, school closure was often followed by a decline in incidence (see Appendix 6), although as discussed earlier it is unclear whether this was due to closure or to the natural dynamics of infection. It is also difficult to assess whether the impact on the general population differed between the strategies. For many settings in which individual schools were closed, incidence data for individuals not attending the affected schools are not presented, whilst analyses of wider closures tended to present data referring to the general population (sometimes not stratified by age).

An alternative to full school closure is the suspension of individual affected classes, as was done during the 2009 pandemic in settings including Taiwan [81, 82] and some schools in Japan [14, 83]. A Japanese study descriptively compared four schools (two elementary and two junior high schools) which suspended classes either individually or simultaneously, and suggested that school closure more effectively interrupted transmission than did class closure [14]. This study also estimated that longer class closures were associated with fewer cases after resumption of classes (rate ratio 0.70, 95% CI 0.56 – 0.88) after adjusting for class grade and whether or not the whole school closed. Interpretation of these results is complicated by the method of ascertainment: parental report to teachers, up to only 7 days after resumption of classes (it is unclear whether cases were ascertained in the same way during class closure). Also, even if closure had no effect, a class which closed for a long period would experience relatively few cases after reopening, as the epidemic would be largely over by that time.

Timing of school closures

Early introduction of non-pharmaceutical interventions, which often included school closures, in US cities during the 1918 influenza pandemic has been found to be associated with a reduction in mortality [70, 75]. Other interventions used in these cities included closure of places such as churches and theatres, quarantine of the infected, and mandatory mask wearing. Earlier introduction of NPIs was also associated with an increased risk of a second wave, due to the presence of an increased number of susceptible individuals when NPIs were discontinued [70, 75]. Earlier introduction of NPIs was associated with a delayed epidemic peak and lower peak and total excess death rates [84]. These effects were not uniform across cities, possibly due at least in part to different timings of the interventions.

In contrast, surveillance data from Abu Dhabi from the 2009 pandemic suggested a steady increase in case numbers over the first four weeks of the summer holiday, even though the holiday began before reported case numbers had started to increase substantially [31]. The extent to which this might be due to increases in ascertainment, especially as influenza surveillance had not been undertaken in this setting before the pandemic, is unclear. Data after schools reopened are not presented. A study of the 2009 pandemic in London also showed little effect of a very early holiday, which in this case lasted one week [32].

In New York City during the 2009 pandemic, closure of individual schools was considered if ≥5 students on any one day, and subsequently ≥2.0% (on one day) or ≥1.0% (on two consecutive days) of students, reported to the school medical room with ILI [17]. In the 64 schools which met these criteria (of which 24 closed), an average of 49% of the total number of ILI cases occurred before the criteria were met, suggesting that a lower threshold might be necessary to substantially curb transmission.

Duration of closure

The duration of school closure varied between studies. In the datasets identified from the 2009 pandemic, closures (considering both planned holidays and reactive closures) most commonly lasted for 7-13 days (e.g. affected UK schools were typically closed for a week), whilst some schools were closed for longer periods (e.g. [13, 64, 80]).

Analyses of the 1918 pandemic in US cities found that the duration of non-pharmaceutical interventions (which usually included city-wide school closures) was negatively associated with the total excess death rate [84]. Since transmission can resume once NPIs are discontinued [70], it has been suggested that they may need to be maintained until vaccines become available [75].

In the datasets reviewed here, closures longer than two weeks were associated with reduced incidence or transmission in several studies of seasonal [85] and pandemic [13, 72] influenza (e.g. a reduction of 70% in the rate of effective contact between school-aged children [13]), but not in others [62, 80]. Two studies which suggested reasonably strong evidence of an effect of school closure, e.g. a 42% reduction in rates of medically attended ARI which was reversed on reopening [8] ,reported on closures lasting two weeks (in France and Israel) [7, 8]. Studies in Japan [34] and England and Wales [65] also suggested possible effects of two-week closures on seasonal influenza.

However, two-week closures did not always appear to reduce transmission [12]. Shorter closures, e.g. of 1-2 weeks, may sometimes have contributed to reductions in transmission [16, 19, 30, 68, 72, 86], but often had no obvious effect [11, 28, 45, 47]. In London, contacts between children were reduced more dramatically during a six-week holiday than during one-week breaks [19]. In contrast, a Chinese study estimated that R_n was reduced during a one-week National Day Holiday, but not during the eight-week summer holiday [25]. These differences are likely to reflect differences in behaviour during particular holidays.

Use of multiple interventions

In most of the pandemic influenza studies, other interventions were implemented alongside school closure and may have contributed to any reduction in incidence. In 2009, antiviral treatment and / or prophylaxis was commonly used in the studies identified [13, 14, 27-30, 33, 36, 37, 39, 43, 48-51, 53, 56-58, 63, 66, 76, 77, 79, 80, 82, 83, 87-89]. Public places were sometimes closed and / or large gatherings were discouraged, restricted or cancelled [20, 27, 52, 53, 64, 68, 73]. Some datasets from the 2009 pandemic included vaccination against the pandemic strain, although this was usually only available late in the study period so would not affect the included incidence data [39, 72, 81, 82, 86, 88]. In 1918, school closures were often combined with other social distancing measures [69, 70, 75, 84]; the only study included from the 1968 pandemic was a vaccine trial [59]. Of the few pandemic studies which mentioned no additional interventions, one suggested an effect of school closures: in Israel in 2009, three waves of infection corresponded to the planned closure and reopening of schools [74]. In the England and Wales data for the 2009 pandemic, other interventions (vaccination and antivirals) were used to only a limited extent; incidence still clearly declined during the school summer holiday and increased afterwards [72].

Some studies of seasonal influenza mentioned additional interventions (e.g. vaccination [44, 90, 91], prophylactic amantadine [92], hygiene promotion [45, 46, 85], closure of public places [85], and advice to avoid large gatherings [47]). However, some studies without additional interventions showed reductions in incidence and / or transmission (e.g. measured as effective contact rates) during school closure [7, 8].

Discussion: Epidemiological studies

The identified epidemiological studies provide evidence that school closures can reduce transmission and incidence of influenza and influenza-like illness amongst children, although the effects on other age groups are less clear. The effects appear to be dependent on timely implementation in relation to the development of the outbreak. There is limited evidence available from which to infer the relative benefits of different closure strategies (e.g. pro-active versus reactive closures, local versus national closures, or the optimal timing or duration of closure).

In some studies, incidence or transmission increased when schools reopened [8, 9, 19, 21, 22, 25, 34, 35, 63, 67, 68, 70, 72, 73, 75, 86]. This apparent reversibility strengthens the conclusion that school closure can cause reductions in influenza incidence, even in some studies in which no additional interventions (beyond usual seasonal interventions) were in use [8, 34]. In many other datasets, multiple interventions were used, so the specific effects of school closures are difficult to isolate.

Results from analyses of seasonal influenza may not be directly applicable to a pandemic. During both seasonal and pandemic outbreaks, schools were often closed for planned holidays rather than as a control measure; contact patterns may differ between reactive school closures [93] and holidays [22]. Furthermore, there may be differences in behaviour during different school holidays and in different countries. This might account for the apparently different effects of the summer and National Day holidays in China [25] and the summer and half term holidays in London [19] (described above).

Extrapolating from previous pandemics may also be problematic. Modelling studies (reviewed below) have predicted that school closures will have the greatest effects if transmission occurs mainly amongst children. The importance of children in transmission has varied between pandemics [94]; in 2009, attack rates were higher in children than in adults, probably because of pre-existing immunity in older individuals [95]. Viral virulence will also influence individuals' responses to school closure and other interventions, e.g. spontaneous social distancing during a mild pandemic may be less dramatic than occurred in 1918. Changes in household size, contact patterns, children's behaviour and school systems since 1918, 1957 and 1968 may also limit the generalisability of experiences from these pandemics.

Strengths and weaknesses of the review

This review has identified relevant studies from a wide variety of settings around the world, relating to both seasonal and pandemic influenza. It extends and updates previous reviews of epidemiological studies of the effects of school closures on the incidence and transmission of influenza [1, 4], by including published experiences from the 2009 influenza pandemic. It does not examine other implications of school closure, such as ethical [96], economic [97, 98] and legal [99] aspects, which must also be considered in policy decisions. These issues have been reviewed, for example in [1].

Publication bias is a possibility, but may be unlikely as many of the studies identified did not aim to evaluate the effects of school closure on transmission and / or found no apparent effect of school closure. Foreign language papers were excluded, but in most cases it was clear from the title and / or abstract (available in English) that the papers were not relevant to this review.

Studies also exist which only studied the growth phase of influenza epidemics in relation to the reopening of schools after holiday closure periods (e.g. during the 1957 [100, 101] and 2009 [102] pandemics). This topic was considered to not address the object of this review (the effect of closure of schools immediately before or during an epidemic) and so were not considered here. The results of such studies do, however, support the conclusion that contact between children at school accelerates epidemic growth, implying that school closure could reduce transmission.

Strengths and weaknesses of the studies

The studies identified were often necessarily somewhat opportunistic or did not specifically aim to investigate how school closure affected incidence or transmission. It is difficult to compare the epidemics and to assess the influence of individual factors (such as the duration of closure, local versus national closures, pro-active versus reactive closures, differences in the population under study (schoolchildren or the wider population) and timing of school closure) on the effects of school closures, due to heterogeneity in these factors between studies.

In many of the studies, it is not possible to separate the effects of school closure from the natural transmission dynamics of infection, particularly when schools were closed late in the epidemic or, as in some cases, after the peak. On the other hand, if schools are closed very early in an outbreak, few data may be available on transmission before school closure, making it difficult to assess the effects of the intervention [13]. In some datasets, the number of cases was small, further complicating the interpretation.

Changes in ascertainment may occur over the course of an outbreak and therefore bias the findings, particularly in the early stages of a pandemic. For example, the Mexican surveillance system developed over the early stages of the 2009 pandemic to include more clinical outcomes (initially surveillance included only hospitalised patients with severe pneumonia, but this was subsequently extended to include influenza-like illness in inpatients and outpatients) [73]. If ascertainment improves during the outbreak, then any reductions in incidence due to school closures (or other measures) could conceivably be masked or diluted. Conversely, the proportion of samples which undergo virological testing may be reduced in the later stages of an outbreak, and in some settings (e.g. New Zealand [63]) patients with ILI were discouraged from consulting GPs during the 2009 pandemic. This would artificially reduce the apparent numbers of confirmed cases and potentially over-estimate the effects of school closures.

These changes in ascertainment were quantified in some studies. The estimated proportion of influenza cases that were reported in Hong Kong declined to ~5% of its original value during the move from containment to mitigation during the 2009 pandemic [13]. In England, the introduction of the National Pandemic Flu Service telephone helpline coincided with the school holiday, and was estimated to have reduced the probability of GP consultation for adults with ILI from 16% to 1.8% [19]. In China, reporting was estimated to be reduced by 20-30% during a national holiday [25].

However, the authors of a study of respiratory virus isolations in Hong Kong during the SARS outbreak felt that increased testing was unlikely to account for the observed reduction in the proportion of specimens which were positive during the period of public health interventions, as this proportion remained low after the number of tests performed returned to normal [85].

Case definitions may not always have been well-suited to detecting any effect of school closure. For example, school absenteeism is a relatively non-specific measure, whilst laboratory specimens frequently represent severe infections (e.g. in the elderly, who may have little contact with children and therefore be relatively unaffected by school closure).

In almost all of the studies of pandemic influenza, other interventions were implemented concurrently with school closure. This adds complexity to any evaluation of the specific role of school closures in reducing incidence.

Results: Modelling studies of school closure during an influenza pandemic

The search strategy used in Medline to identify studies which modelled the effects of school closure on pandemic or epidemic influenza is given in Appendix 2.

General characteristics of the modelling studies

Figure 2 describes the results of the search for modelling studies and the selection of papers. 1976 papers were identified by the searches of Medline and Embase, of which 146 were assessed as being potentially eligible and read in full. The 45 studies that were finally included in the review comprised 40 identified through the electronic databases, 2 identified through Pubmed, 1 from handsearching, 1 from reference lists and 1 from other collections.

Figure 2: Identification of mathematical modelling studies of the effects of school closure on influenza outbreaks

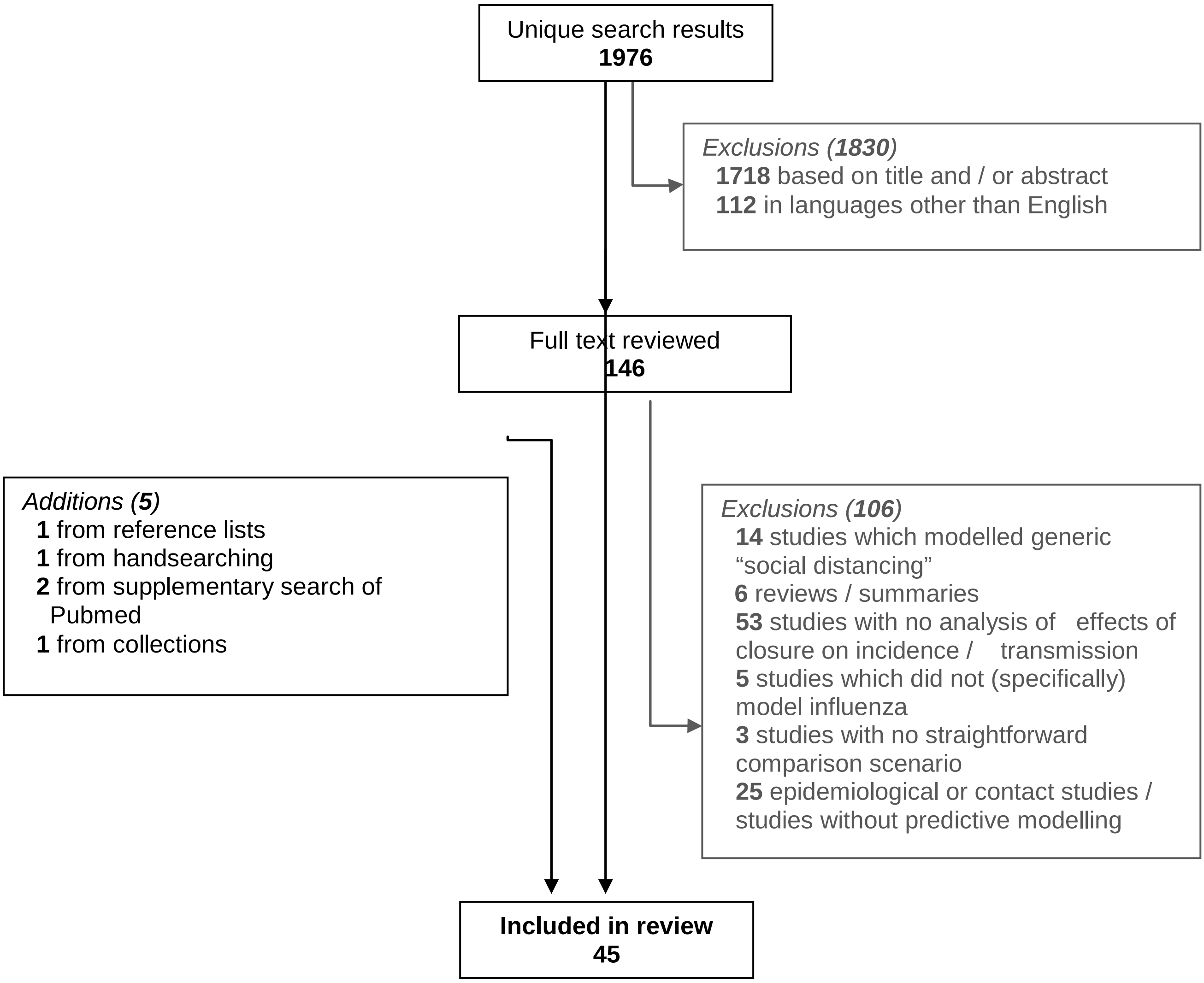


Table 3 summarises the key features of the 45 included mathematical modelling studies of the effects of school closures on influenza transmission (some studies used essentially the same model to address different research questions, as described in Appendix 9). The studies identified used models of three main types: compartmental models, individual-based models, and network models (see Box 1 for definitions).

Most of the studies (30/45) used individual-based models; a further 5 used network models and 9 compartmental models (see Table 3 and Appendix 9). One additional study (referred to as "other" in Table 3) used a household model describing transmission within and between households and in the community and workplaces. The assumed effect of school closures on contact patterns varied between studies, was not always explicit, and was rarely based on empirical data. Almost all of the studies which stated these assumptions assumed that contact between children (or contact occurring at school) either decreased or was eliminated during school closures, whilst contacts made by other age groups or outside school were either unaffected or increased (15 and 11 studies respectively). Three studies, however, estimated the effects of school closures on contact patterns by fitting the models to incidence data spanning periods during which schools were open and closed (these studies are also included in the review of epidemiological studies) [7, 10, 68]. Two further studies used empirical data on contact patterns collected during term time and a school holiday [103, 104].

Almost all studies (40/45) measured the impact of school closures using the change in the overall cumulative attack rate predicted to result from school closure, whilst many also provided information on the effects on the peak incidence of infection (33/45) and / or the time course of the epidemic (32/45) (Appendix 9).

Table 3: Features of modelling studies identified

	No. of papers
Total papers	**45**
Type of model	
Individual-based	30
Network	5
Compartmental	9
Other	1
Baseline age-specific ARs	
Higher in children than in adults	27
Relatively uniform with age (e.g. based on 1968 pandemic)	3
Not age-structured	3
Age-specific ARs not given or basis not stated	15
Threshold for closing schools*	
Pre-emptively or immediately at start of pandemic	6
Based on case numbers or incidence of infection (e.g. 50 cases per 100,000 pop.)	16
Based on cumulative incidence of infection	6
Based on prevalence of infection	8
Based on time since beginning of pandemic or local epidemic (e.g. 2-8 weeks)	12
Unclear / not stated / based on observed timing	4
Assumed effects of school closures on contact rates*	
Child-to-child/school-related contact reduced or eliminated, no effects on other contacts	15
Child-to-child/school-related contact reduced or eliminated, other contacts increased	11
Child-to-child/school-related contact reduced, other contacts increased or decreased depending on location	2
Complex changes based on empirical contact data	2
Uniform reduction in contact rates (model not age-structured)	3
Not stated / unclear	12
Basis of assumptions regarding effects of school closures on contact rates	
Empirically measured contact rates	2
Fitting of model to incidence data	3
Other quantitative data	1
No empirical basis stated	40
Information provided on effects of school closure on:	
Cumulative AR	40
Peak incidence of infection (or peak prevalence)	33
Time course of epidemic (duration and / or time to peak)	32
Sensitivity analysis / exploration of different values of:	
R_0	24
Baseline contact rates	6
Changes in contact rates associated with school closure	6
Patterns of age-specific ARs	6
Threshold for closing schools (measured as incidence or time since start of epidemic)	19
Duration of closure	16
Threshold for re-opening schools	3

*Each paper may explore more than one assumption

Box 1: Definitions

Compartmental models stratify individuals into different categories (“compartments”) and are usually described using the compartments included. For example, SEIR models include compartments for those who are susceptible to infection (S), infected but not yet infectious (E), infectious (I), and recovered (R). Such models may be deterministic, in which case they describe what happens on average in the population, or stochastic, i.e. allowing for random events to influence the course of the epidemic. In compartmental models, individual members of the population are not followed, but the number of individuals in each compartment is tracked over time.

Individual-based models explicitly follow each individual in the modelled population; each person can be assigned characteristics such as age and employment status which determine (amongst other things) their interactions with other people and therefore their probability of becoming infected.

Network models are individual-based in that each person is explicitly tracked, but transmission of infection can occur only along links in a pre-specified network of contacts.

Matrices of “who acquires infection from whom” (WAIFW matrices) describe the rate at which individuals in different groups (e.g. age groups) come into effective contact in a modelled population. An *effective contact* is defined as one that is sufficient to lead to transmission if it occurs between a susceptible and an infectious individual.

Assortativity refers to the extent to which different groups (e.g. age groups) in a modelled population contact each other. If mixing is highly assortative, individuals are more likely to contact others within their own group than they are to contact individuals in other groups. If mixing is disassortative, individuals are more likely to contact individuals in different groups than they are to contact individuals in their own group.

Predicted effects on peak and cumulative attack rates

Most models predicted that reductions in the peak incidence and cumulative attack rate would be achieved by closing schools (Figures 3 and 4).

Figure 3: Summary of the estimated effects of school closures on peak incidence of pandemic influenza (all ages) predicted by the modelling studies. Different symbols are used for the assumed value for R_0. The findings are grouped as to whether they assumed that the community/household contacts increased, remained unchanged, the assumptions about contact were based on empirical data or were unclear. Some studies assumed that workplaces and/or other public places also closed (9, 13, 18). All studies that stated their assumptions regarding the effects of school closure on contact patterns assumed that contacts between school-aged children were reduced or eliminated.

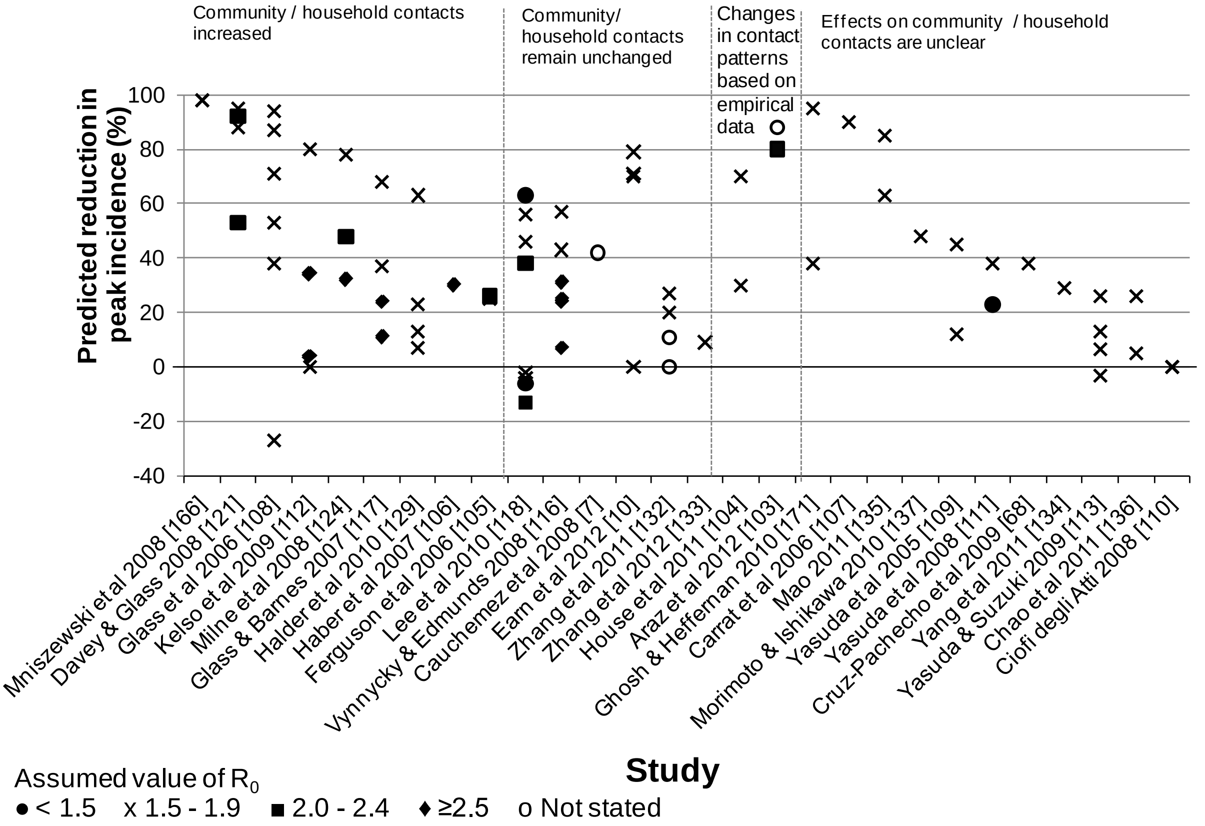
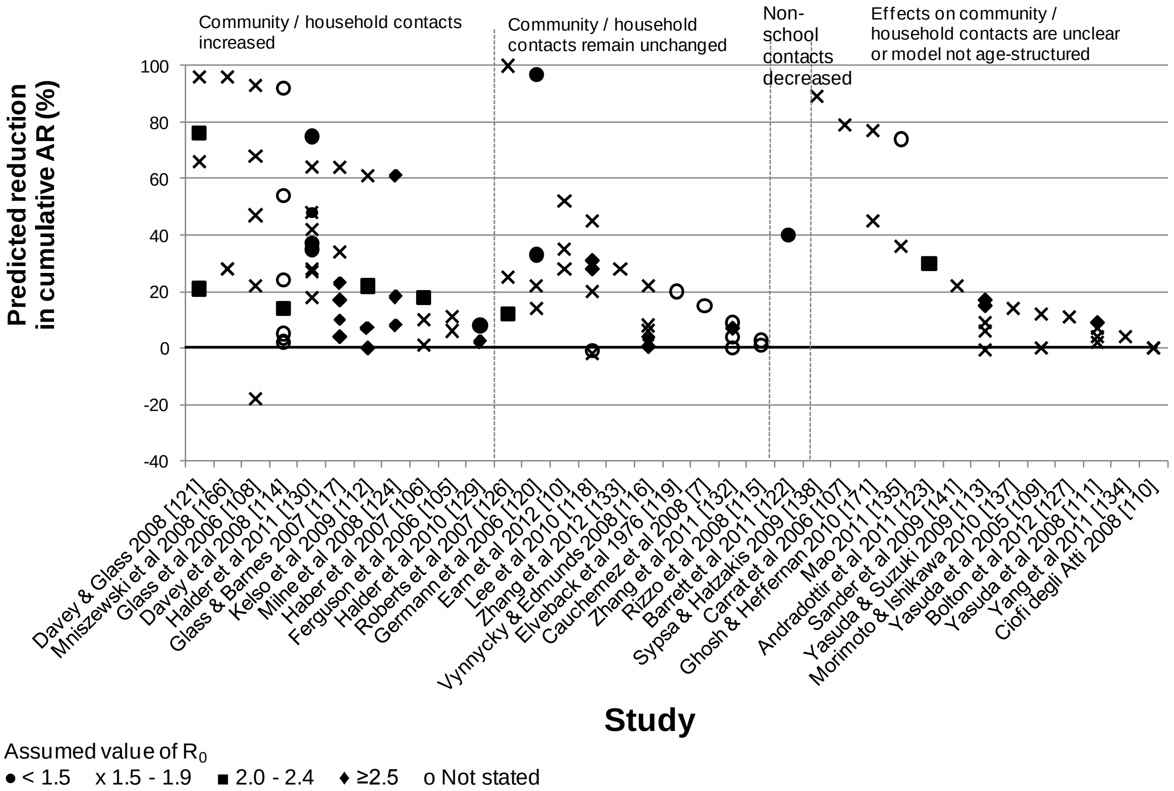
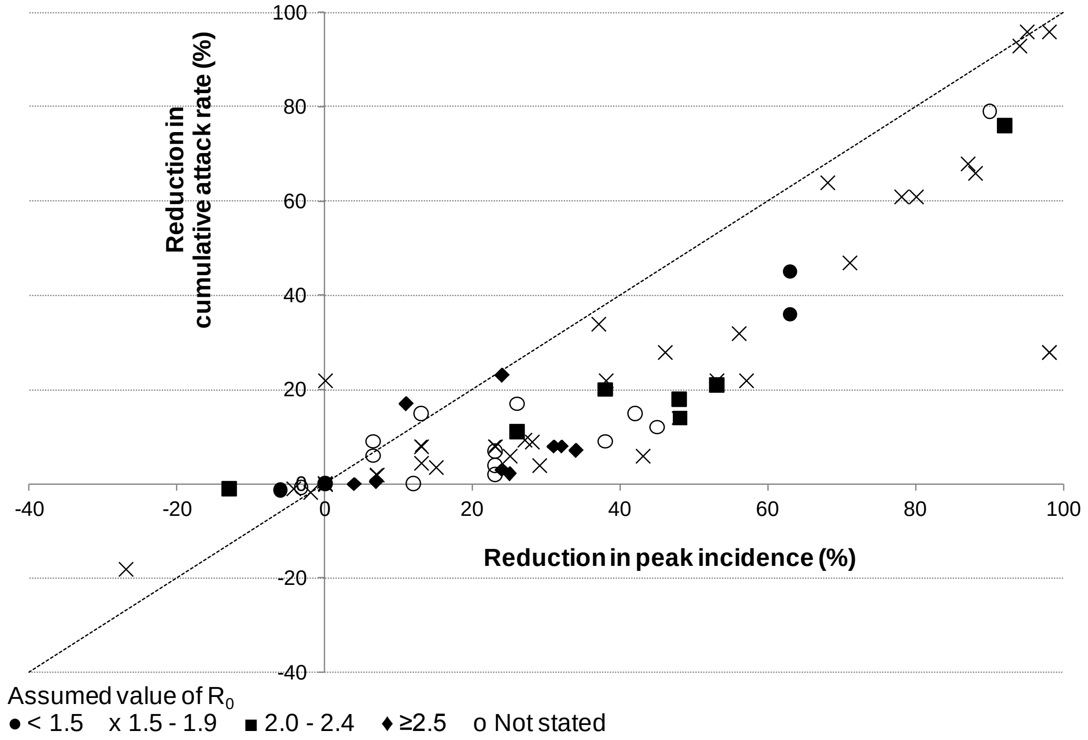


Figure 4: **Summary of the estimated effects of school closures on cumulative incidence of pandemic influenza (all ages) predicted by the modelling studies. Different symbols are used to reflect the assumed value for R_0. The findings are grouped according to whether they assumed that the community/household contacts increased, remained unchanged, the assumptions about contact were based on empirical data or were unclear. Some studies assumed that workplaces and/or other public places also closed (9, 18, 23). All studies that stated their assumptions regarding the effects of school closure on contact patterns assumed that contacts between school-aged children were reduced or eliminated.**



Typically a 20-60% reduction in the peak incidence was suggested (e.g. [105, 106]). The size of the reduction varied from ≥90% [107] to an increase of 27% [108] (Appendix 9, Figure 3). In general, the predicted reductions in the cumulative AR were smaller than those in the peak incidence (Figure 5), with several studies predicting small (e.g. <10%) or no reduction in the cumulative AR (e.g. [105, 106, 109-118]) and a few predicting substantial reductions (≥90% in some cases, e.g. [108, 114, 119-121]). Only two studies [108, 118] predicted that the peak incidence might increase markedly (by up to 27%) under some circumstances following school closures, e.g. if school closures led to a doubling in the number of contacts in the household and community [108]. Of these two studies, one predicted that the cumulative AR would increase by 18% [108] whilst the other did not predict substantial increases in the cumulative AR under any of the scenarios investigated [118].

Figure 5: Plot of the predicted reduction in the cumulative attack rate against that in the peak incidence (all ages). Each marker represents the results of one analysis. Different symbols are used to reflect different values for R_0.



Studies exploring the effects of school closures on age-specific peak incidence or cumulative attack rates typically found that the reductions in both were greater for children than for adults [7, 10, 103, 104, 107, 109, 112, 116, 122]. For example, closing schools at a threshold incidence of 23 cases /100,000/day might reduce peak incidence by 51% in children and 41% in adults, and the cumulative AR by 21% in children and 12% in adults [7]. However, one study (which included a 20% reduction in workplace and community contacts as well as an unspecified reduction in contact between children) predicted the largest reductions in the cumulative AR for middle-aged and older adults (~40%, compared 22% for schoolchildren) [123].

In general, the size of the reductions resulting from school closures depended on four key factors, namely the basic reproduction number (R_0), the amount by which contact between children was assumed to have changed because of school closures, the timing of school closures, and the underlying contact patterns between children before schools were closed. However, the extent to which these individual factors affect transmission is difficult to quantify based on these modelling studies, since the assumptions about each of these factors differed between the studies. Despite this, some results emerged consistently, with the greatest reductions being predicted to occur when:

i) **R_0 was low** (e.g. <2) [103, 108, 112, 114, 116-118, 120, 121, 124-126]**.** For example, according to one analysis based on age-specific attack rates from the 1968 influenza pandemic, which assumed that school closures completely eliminated contact between schoolchildren, the peak incidence of infection could be reduced by 78% if R_0 = 1.5 and 32% if R_0 = 2.5 [124]. If R_0 is sufficiently low, the reductions in contact resulting from school closures may reduce the effective reproduction number to less than one so that the incidence starts to decrease and the subsequent epidemic is small. If R_0 is high, however, the same reductions in contact are less likely to be sufficient for this to occur. One study was an exception to this, predicting the greatest reduction in the peak demand for intensive care unit (ICU) beds when R_0 was high [104].

ii) **School closures were assumed to lead to large reductions or complete elimination of contact between school-aged children** [7, 108, 116, 121]**.** For example, the peak incidence could be reduced by 92% or 54% if contact was reduced by 90%

or 50% respectively and the cumulative AR by 76% or 22% for the same reductions in contact [121].

iii) **Schools were assumed to close relatively early in the epidemic whilst the incidence was still low [7, 106, 112, 114, 117].** Generally, early closures were associated with the greatest reductions in peak incidence. For example, if schools were closed when incidence exceeded 100 cases/100,000/day, the peak incidence might be reduced by 42%, but would decrease by only 21% if the threshold was 1000 cases/100,000/day [7]. The corresponding reductions in the cumulative AR were 15% and 10% [7]. However, the optimum timing of closure depends in part on its duration (this is discussed further below).

iv) **Age-specific ARs were higher in children than in adults (as in the 1957 pandemic), as compared to the situation where they varied little with age (as in 1968)**.[108, 117, 119, 124, 127]. For example, one model predicted that the cumulative AR could be reduced by 90% if age-specific attack rates were similar to those of the 1957 pandemic but by only 27% if the 1968 age-specific attack rates applied [119]. Similarly, the smallest impacts on the cumulative AR were predicted when mixing in schools at baseline was assumed to be least intense [106, 124], or when mixing was most assortative (i.e. individuals mixed mainly with others in their age group) [116].

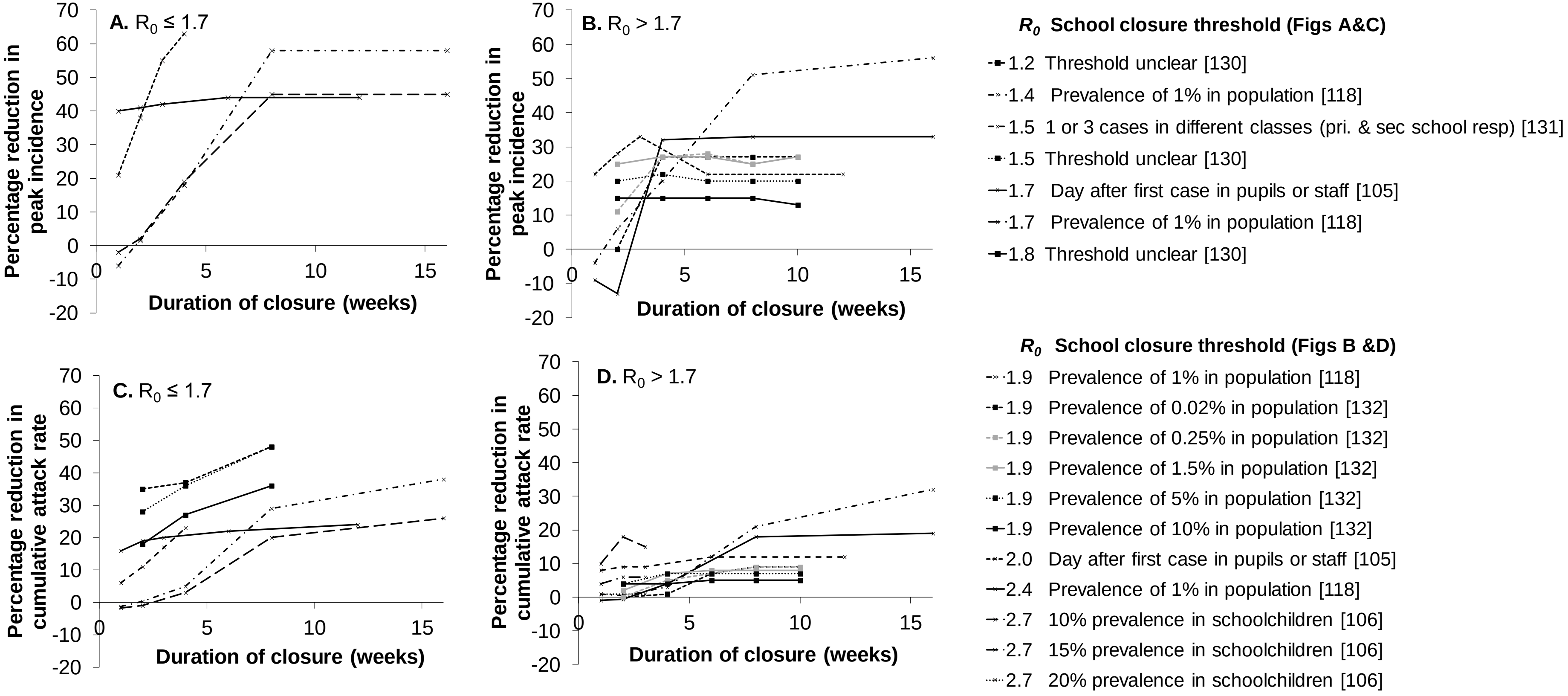
Several studies explored the effect of the duration of school closure on the peak and / or cumulative incidence [68, 103, 105, 106, 109, 113, 118, 119, 128-133]. Of these, eight modelled different durations of closure measured in weeks [103, 105, 106, 118, 129, 130, 132, 133] (Figure 6); one modelled durations of closure ranging from 4-7 days [113] and five compared temporary closures (of 7-60 days) with permanent closures [68, 109, 119, 128, 130].

Several studies reported that the impact of school closures increased with the duration of closure (Figure 6), although increasing the duration above 8 weeks generally had little extra benefit. One study suggested that peak and cumulative attack rates could increase slightly if schools were closed for two weeks or less [118], but the other studies shown in Figure 6 did not predict such increases [105, 106, 129, 130].

However, several studies found that the effect of school closures depended on both the duration of closure and the time (or incidence) at which schools were closed [103, 131-133]. Intermediately timed closures were often predicted to be more beneficial than closures occurring very early or very late in the epidemic [131, 132] (although very late closures were consistently predicted to be relatively ineffective). The optimum threshold for closure depended on the duration, e.g. if schools were closed for <8 weeks then the higher the threshold, the lower the cumulative AR (incidence thresholds up to 5% were investigated), whereas if closure lasted longer, a lower threshold (e.g. 1.5%) was optimum [133]. One study assessed the effects of varying the threshold and duration of school closure on cumulative ARs in adults and children [103]. For R_0 between 1.1 and 1.5, closures lasting ≤4 weeks led to increases in adult ARs but decreases amongst children; for both children and adults the benefits of school closure increased with duration, but increasing the duration of closure above 12 weeks had little extra benefit.

All five studies which compared temporary and permanent closures predicted the greatest reductions in peak and / or cumulative attack rates with permanent closure [68, 109, 119, 128, 130]. One study argued that the duration of closure was more important than the closure threshold in determining the effect on the epidemic, and that schools should close for at least eight weeks [118]. Some studies predicted reasonably large effects with shorter closures than this, e.g. reductions of 38% [129] or 41% [105] in the peak incidence if closure lasted for two weeks. One further study estimated the effects of closing schools for 4-7 days; in this model, the benefit increased with duration of closure even over this limited range (e.g. the cumulative attack rate was almost unaffected by a four-day closure but was reduced by 15% if schools were closed for 7 days) [113].

Figure 6: Influence of the duration of school closure on the predicted effects on pandemic influenza. Reductions in peak incidence (A and B) and cumulative attack rates (C and D) for different values of R_0 and assumed thresholds for school closure. Lines join predictions from the same model using the same sets of assumptions.



Predicted effects on the time to peak and the duration of the epidemic

Most models predicted that closing schools would delay the peak of the epidemic, usually by no more than 1-3 weeks [68, 105, 108-110, 112, 113, 116, 118, 129, 133-136], but one model suggested that school closure would not affect the timing of the epidemic peak [107]. A few studies suggested that school closures could bring the peak forward compared to the unmitigated epidemic [103, 106, 108, 112, 135]. When an earlier peak was predicted, the peak was generally lower and the incidence remained high for longer than in the unmitigated scenario.

Increases in the overall duration of the epidemic of 1-3 weeks were commonly predicted [68, 106, 109, 112, 117, 118, 134], with some models predicting increases of about a month [10, 107, 111, 135, 137] or more [108, 116]. Four studies suggested that school closures could shorten the epidemic (by 11 days [138], 2-3 weeks [108, 122], ~1-3 months [103]), whilst another found little effect on the duration [113].

These predictions depended on assumptions about R_0, the reduction in contact resulting from school closures, the threshold incidence at which schools were closed, and the extent to which attack rates were age-dependent. For example, high values of R_0 were commonly associated with the smallest effects on both the delay to the peak [105, 116-118] and the duration of the epidemic [112, 116, 117].

Other measures of effect

As well as considering cumulative attack rates, peak incidence and the time course of the epidemic, some studies measured the effectiveness of school closures using other outcomes.

Ferguson et al suggested that closing 90% of schools and 50% of workplaces within 5km of a detected case for three weeks would have a >90% probability of preventing an outbreak if R_0 was 1.7 or less and antiviral prophylaxis was provided simultaneously [139]. Timpka et al estimated that the reproduction number would be reduced from 2.23 to below 1 if all schools were closed, but not if only high schools or day-care centres were closed [140].

A few studies evaluated the potential effects of school closures on hospitalisations and deaths. One study predicted a large reduction in hospitalisations (79%) if schools were closed [107]; another suggested a smaller reduction of 23% [141]. A further study modelled the effects of school closures on demand for ICU beds, predicting that peak demand could be reduced by 30-70% by optimally timed closures [104]. Another predicted that deaths could decrease by up to ~17% but could also increase by almost 10%, again depending upon the threshold for and duration of closure [106]. Deaths and hospitalisations were related to the threshold and duration of closure in a less straightforward way than were illness rates in this model, as school closure increased transmission in households and the community and thus to individuals outside the school age range, for whom the probabilities of hospitalisation and death given infection were greater than those among individuals of school age [106].

Reopening schools

The question of when schools can safely be reopened has been addressed in detail in one modelling analysis [121]. This suggested that the threshold at which schools were reopened determined whether the epidemic recurred: the higher the threshold incidence for reopening, the more likely the epidemic was to recur, potentially resulting in multiple peaks in incidence. Another modelling analysis suggested that the benefit of closing schools was not reduced substantially as long as the prevalence of infection in children was <1% when schools reopened [117]. Maintenance of school closures indefinitely might be seen as equivalent to considering closure until a vaccine is available [112].

Local versus national closures

Modelling analyses of the relative benefits of three possible school closure strategies (national, local or individual school closures) have produced inconsistent results. One study suggested that a policy of “area closure,” in which all schools within 10km of a case closed for a fixed period, produced similar results to a policy in which each school closed following a case in that school [105]. Similarly, another study found no consistent differences between the effects of closing individual schools and closing an entire school system [118], although two others suggested that closing individual schools would be more effective than closing all schools simultaneously [129, 136]. A slightly different situation, in which some communities closed schools while neighbouring communities did not, and mixing between these communities occurred, reduced the effectiveness of school closure [121].

Thus it is not clear from the modelling studies whether there is any difference in effectiveness between closure of individual schools, multiple schools in a local area, or all schools nationally. Most of the studies modelled closure on a large (e.g. national) scale; those which investigated alternative strategies did not consistently find one strategy to perform better than others.

Discussion: Modelling studies

Published mathematical models of the effects of school closures during influenza outbreaks have reached a variety of conclusions about their effects on the course of the epidemic. The predicted effects on the peak incidence ranged from reductions of >90% to an increase of 27% but were frequently in the range 20-60%. Predicted effects on the cumulative attack rate were consistently smaller than those on the peak incidence (e.g. 0-40%) but were also variable: the predicted effects on the peak incidence ranged from reductions of >90% to an increase of 18%, although most studies predicted reductions in both the cumulative and peak attack rates. These predictions suggest that an important benefit of school closures, if they are timed appropriately and other conditions are optimal, would be in reducing the peak burden on health services and in delaying transmission in the population until other interventions (e.g. vaccination) become available.

Several factors were consistently found to influence model estimates of the effects of school closures on measures such as the cumulative attack rate and the peak incidence of infection. For example, school closures are usually expected to be more effective at reducing transmission if R_0 is relatively low (e.g. <2, see Figures 3 and 4) and if age-specific attack rates are higher in children than in adults (or if contact intensity in schools is high). These findings illustrate that such factors should ideally be considered when deciding whether to implement a school closure policy during an infectious disease outbreak, although such information may not be readily available in the early stages of an epidemic of a newly emerging pathogen. The benefits of school closure also depend on the threshold for and duration of closure, and these two factors interact to influence the reductions in peak and cumulative attack rates. For example, closing schools very early may have less effect than closing them later, depending on the duration of closure [103, 132, 133]. This has been attributed to resumption of mixing between susceptible children when schools reopen while influenza is still circulating, allowing them to acquire and transmit infection [118]. The benefits of school closure are generally predicted to increase with the duration of closure, but increasing this duration above 8 weeks may have little additional benefit.

In many of the epidemiological studies reviewed in Section 6, reactive school closures lasted for 1-2 weeks. In the modelling studies, closures of this duration were usually predicted to have little effect on the cumulative AR, typically reducing it by ≤10%. However, one study predicted a reduction of up to 35% in the cumulative AR, if R_0 was 1.2 and closure lasted two weeks [130], and another predicted a reduction of 18% even if R_0 was as high as 2.7, if schools closed when the prevalence of infection in schoolchildren reached 10% [106]. The predicted effects of 1-2 week closures on the peak AR were greater than those on the cumulative AR. Three estimates from two studies predicted reductions in the peak AR of >20% with a one-week closure: 21% [131], 22% [105] and 40% [105].

Strengths and weaknesses of the modelling review

Previous reviews [124, 142] have summarised the effects of school closures predicted by some of the individual- and network based models [105, 108, 120, 139] included here. Models of multiple simultaneous interventions (including school closures) have also been reviewed [143]. This review of modelling analyses of school closures complements the review of the epidemiological evidence of the effect of school closures, in suggesting key factors that may affect the extent to which school closures are beneficial during a pandemic (e.g. the effective reproduction number and the relative extent of mixing outside schools).

As for the review of epidemiological studies, the initial screening of titles and abstracts for the modelling review was carried out by a single reviewer and the papers included were restricted to the English language. However, most papers which were identified in the initial literature search and were not in English appeared not to be relevant to the review.

Strengths and weaknesses of the studies

Models are necessarily a simplification of reality and, as has been noted [142], their results should be considered indicative rather than absolute predictions (e.g. it has been pointed out that models generally do not incorporate changes in the “social order” which might occur during a pandemic [140]). Whilst the precise quantitative predictions are sensitive to viral properties which may not be known in detail at the beginning of a pandemic, certain findings are reasonably consistent (see Section 7) and may be useful for formulating policy in the early stages of an outbreak. For example, if it is clear early on that adults are infected as frequently as children, school closure may be a less efficient strategy than if attack rates are much higher in children than in adults.

A wide range of assumptions have been made in the transmission models, particularly regarding population contact patterns (Table 3). This is largely because there have historically been few datasets available from which the effects of school closures on contact patterns can be estimated (recently, however, such data have been published for routine [22, 144-147] and reactive [93] school closures). Despite this uncertainty, it is fairly uncommon for models to explore the effects of varying their assumptions about how school closures influence contact patterns (exceptions include [7, 108, 114, 116, 121, 127]). This is an important limitation of much of the published literature, as predictions of the effects of school closure depend upon how individuals contact each other (and thus transmit infection) whilst schools are closed and while they are open. The available data show that people make fewer contacts during school holidays and weekends than on weekdays during term time [145, 146], but these recently published datasets have rarely been incorporated into models. Several recent modelling studies did, however, estimate the effects of school closures on contact patterns using either empirical data or modelling techniques [7, 10, 68, 103, 104].

Conclusions and implications

A growing body of evidence suggests that school closure can reduce transmission of influenza. However, this effect is not seen consistently, and its likely magnitude, as well as the optimum timing and duration, remain unclear. There are several reasons for this uncertainty:

1. In many published epidemiological studies and outbreak reports, school closure was implemented relatively late in the outbreak, at which point incidence may have begun to decline even if schools remained open.
2. During outbreaks (both seasonal and pandemic), the use of multiple interventions often makes it difficult to assess the effects of school closures alone.
3. It is unclear to what extent changes in contact patterns and transmission occurring during seasonal influenza and past pandemics may be extrapolated to a future pandemic. Data from the 2009 pandemic support the conclusion that school closures can reduce transmission of influenza in contemporary settings; however, the results from these studies may not be applicable to a new pandemic virus which may have different epidemiological properties (e.g. a higher case fatality ratio or more uniform age-specific attack rates than those seen during previous pandemics).
4. Mathematical modelling studies have also reached varying conclusions regarding the magnitude of the effects of school closures on an influenza pandemic, due to differences in their underlying assumptions regarding both viral properties and human behaviour.
5. Past pandemics have varied in important characteristics which influence the effects of school closures (e.g. age-specific attack rates), and the features of a future pandemic cannot be predicted.

Several conclusions can be drawn from the identified published literature:

1. The fact that some epidemiological studies showed increases in incidence after schools reopened suggests that school closures can reduce transmission under certain circumstances.
2. The timing of school closure is likely to be critical, with the intervention likely to be more effective if implemented relatively early in the epidemic, although this also depends on the duration of closure. However, there is limited evidence available regarding both the optimal timing and duration of closure from either the epidemiological or modelling literature. A limit at which it is “too late” to close schools is not currently demonstrated in the limited literature available.
3. School closures are able to reduce transmission amongst children. Evidence regarding the effects on adults is less consistent, but generally transmission amongst adults appears to be relatively unaffected by school closures.
4. Both epidemiological and modelling studies have found that the peak and cumulative attack rates can be reduced by school closures. The extent of these reductions is however unclear, and likely to depend on many factors including population behaviour, viral transmissibility and age-specific attack rates. Modelling studies consistently predict that school closure would have a greater effect on peak than cumulative attack rates.
5. Modelling studies indicate that school closures are likely to achieve the greatest reductions in peak incidence and cumulative attack rates if the transmissibility of the causative virus is relatively low and if attack rates are higher in children than in other age groups.
6. Reactive local closures and pro-active national closures both appear to have had an effect on transmission. However, further work is required to assess the relative benefits of different school closure strategies.

Implications for public health policy

It is reasonable to continue to consider school closure as a component of a mitigation strategy during pandemic influenza, e.g. before an effective vaccine becomes available. The intervention can reduce transmission amongst children and possibly amongst adults. There is however insufficient evidence to suggest a particular school closure policy (e.g. reactive or pre-emptive) over another.

Policy may need to be responsive to the particular features of any future pandemic virus. For example, if substantial transmission occurs in schools (as during the 2009 pandemic) then there is stronger justification for school closure than in the situation where much transmission occurs elsewhere. In the early stages of a pandemic, when important factors such as transmissibility and age-specific attack rates may not be known, a cautious approach (i.e. closing schools in the absence of strong evidence that this will reduce transmission) might be considered, particularly if the virus is believed to be highly pathogenic. As the aim of school closure is to reduce contact between children, school closure should be accompanied by advice that children should avoid meeting in large groups.

School closure has important implications for both children and parents. For example, parents may need to take time off work, work from home or make alternative childcare arrangements. Children may be left at home unsupervised, be deprived of school meals or miss important lessons or exams. These secondary effects may not affect all sections of society equally, e.g. they may be particularly prominent where free school meals are an important source of nutrition or where parents are unable to take time off work or work from home. Whilst a full discussion of such effects is beyond the scope of this review, the extent to which they can be tolerated will depend partly upon the severity of the infection and partly on societal and civic flexibility and preparedness for extreme events.

Implications for further research

Given the nature of the intervention, it may be difficult to plan and conduct very high quality epidemiological studies. However, there are several areas in which further research, or the results of ongoing research, would be valuable:

1. Further transmission modelling based on datasets collected during the 2009 pandemic in settings where schools were closed, and of seasonal influenza outbreaks coinciding with school holidays. Comparative analysis of outbreaks during which schools were closed at different points in the outbreak and for different lengths of time may be particularly useful.
2. Collection of empirical data on both children’s and adults’ contact patterns during term time, school holidays and ideally periods of unplanned closure (due to infectious disease outbreaks or possibly for other reasons such as bad weather). Whilst such studies might be logistically challenging, such data would improve the reliability of predictions of the effects of school closures on the course of an influenza pandemic.
3. Further consideration of the results of modelling studies in relation to what is likely to be achievable in practice, e.g. in terms of the optimum timing and duration of school closure.

References

1. Cauchemez, S., et al., *Closure of schools during an influenza pandemic.* The Lancet Infectious Diseases, 2009. **9**(8): p. 473-81.
2. Reichert, T.A., et al., *The Japanese experience with vaccinating schoolchildren against influenza.* N Engl J Med, 2001. **344**(12): p. 889-96.
3. World Health Organization, *Reducing transmission of pandemic (H1N1) 2009 in school settings. A framework for national and local planning and response*. 2009.
4. Bell, D.M. and World Health Organization Writing Group, *Non-pharmaceutical interventions for pandemic influenza, national and community measures.* Emerging Infectious Diseases, 2006. **12**(1): p. 88-94.
5. Aledort, J.E., et al., *Non-pharmaceutical public health interventions for pandemic influenza: an evaluation of the evidence base.* BMC Public Health, 2007. **7**: p. 208.
6. *Human infection with new influenza A (H1N1) virus: WHO Consultation on suspension of classes and restriction of mass gatherings to mitigate the impact of epidemics caused by influenza A (H1N1), May 2009.* Weekly Epidemiological Record, 2009. **84**(27): p. 269-71.
7. Cauchemez, S., et al., *Estimating the impact of school closure on influenza transmission from Sentinel data.* Nature, 2008. **452**(7188): p. 750-4.
8. Heymann, A., et al., *Influence of school closure on the incidence of viral respiratory diseases among children and on health care utilization.* Pediatric Infectious Disease Journal, 2004. **23**(7): p. 675-7.
9. Heymann, A.D., et al., *School closure may be effective in reducing transmission of respiratory viruses in the community.* Epidemiology & Infection, 2009. **137**(10): p. 1369-76.
10. Earn, D.J., et al., *Effects of school closure on incidence of pandemic influenza in Alberta, Canada.[Summary for patients in Ann Intern Med. 2012 Feb 7;156(3):I28; PMID: 22312154].* Annals of Internal Medicine, 2012. **156**(3): p. 173-81.
11. Rodriguez, C.V., et al., *Association between school closure and subsequent absenteeism during a seasonal influenza epidemic.* Epidemiology, 2009. **20**(6): p. 787-92.
12. Cowling, B.J., et al., *Effects of school closures, 2008 winter influenza season, Hong Kong.* Emerging Infectious Diseases, 2008. **14**(10): p. 1660-2.
13. Wu, J.T., et al., *School closure and mitigation of pandemic (H1N1) 2009, Hong Kong.* Emerging Infectious Diseases, 2010. **16**(3): p. 538-41.
14. Uchida, M., et al., *Effect of short-term school closures on the H1N1 pandemic in Japan: A comparative case study.* Infection, 2012. **40**(5): p. 549-556.
15. Briffault, O., *Weekly influenza-like-illness rates were significantly lower in areas where schools were not in session in the United States during the 2009 H1N1 pandemic.* PLoS Currents, 2011(ecurrents.RRN1234).
16. Copeland, D.L., et al., *Effectiveness of a School District Closure for Pandemic Influenza A (H1N1) on Acute Respiratory Illnesses in the Community: A Natural Experiment.* Clin Infect Dis, 2012.
17. Egger, J.R., et al., *The effect of school dismissal on rates of influenza-like illness in New York City schools during the spring 2009 novel H1N1 outbreak.* Journal of School Health, 2012. **82**(3): p. 123-30.
18. Alonso, W.J., et al., *Comparative dynamics, morbidity and mortality burden of pediatric viral respiratory infections in an equatorial city.* Pediatric Infectious Disease Journal, 2012. **31**(1): p. e9-e14.
19. Birrell, P.J., et al., *Bayesian modeling to unmask and predict influenza A/H1N1pdm dynamics in London.* Proceedings of the National Academy of Sciences of the United States of America, 2011. **108**(45): p. 18238-18243.
20. Chowell, G., et al., *Spatial and temporal characteristics of the 2009 A/H1N1 influenza pandemic in Peru.* PLoS ONE [Electronic Resource], 2011. **6**(6): p. e21287.

21. Chowell, G., et al., *Characterizing the epidemiology of the 2009 influenza A/H1N1 pandemic in Mexico.* PLoS Medicine / Public Library of Science, 2011. **8**(5): p. e1000436.
22. Eames, K.T.D., et al., *Measured dynamic social contact patterns explain the spread of H1N1v influenza.* PLoS Computational Biology, 2012. **8**(3).
23. Flasche, S., et al., *Different transmission patterns in the early stages of the influenza A(H1N1)v pandemic: a comparative analysis of 12 European countries.* Epidemics, 2011. **3**(2): p. 125-33.
24. Hens, N., et al., *Robust reconstruction and analysis of outbreak data: influenza A(H1N1)v transmission in a school-based population.* American Journal of Epidemiology, 2012. **176**(3): p. 196-203.
25. Yu, H., et al., *Transmission dynamics, border entry screening, and school holidays during the 2009 influenza A (H1N1) pandemic, China.* Emerging Infectious Diseases, 2012. **18**(5): p. 758-766.
26. Wheeler, C.C., L.M. Erhart, and M.L. Jehn, *Effect of school closure on the incidence of influenza among school-age children in Arizona.* Public Health Reports, 2010. **125**(6): p. 851-9.
27. Huai, Y., et al., *A primary school outbreak of pandemic 2009 influenza A (H1N1) in China.* Influenza & Other Respiratory Viruses, 2010. **4**(5): p. 259-66.
28. Calatayud, L., et al., *Pandemic (H1N1) 2009 virus outbreak in a school in London, April-May 2009: an observational study.* Epidemiology & Infection, 2010. **138**(2): p. 183-91.
29. Strong, M., et al., *Adverse drug effects following oseltamivir mass treatment and prophylaxis in a school outbreak of 2009 pandemic influenza A(H1N1) in June 2009, Sheffield, United Kingdom.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2010. **15**(19): p. pii/19565.
30. Kawaguchi, R., et al., *Influenza (H1N1) 2009 outbreak and school closure, Osaka Prefecture, Japan.* Emerging Infectious Diseases, 2009. **15**(10): p. 1685.
31. Ahmed, F., et al., *Early outcomes of pandemic influenza (H1N1) 2009 surveillance in Abu Dhabi Emirate, May-August 2009.* Eastern Mediterranean Health Journal, 2012. **18**(1): p. 31-36.
32. Balasegaram, S., et al., *Patterns of early transmission of pandemic influenza in London - link with deprivation.* Influenza and other Respiratory Viruses, 2012. **6**(3): p. e35-e41.
33. Carrillo-Santisteve, P., et al., *2009 pandemic influenza A(H1N1) outbreak in a complex of schools in Paris, France, June 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2010. **15**(25): p. 24.
34. Fujii, H., et al., *Evaluation of the school health surveillance system for influenza, Tokyo, 1999-2000.* Japanese Journal of Infectious Diseases, 2002. **55**(3): p. 97-98.
35. Petrovic, V., et al., *Overview of the winter wave of 2009 pandemic influenza A(H1N1)v in Vojvodina, Serbia.* Croatian Medical Journal, 2011. **52**(2): p. 141-150.
36. Rajatonirina, S., et al., *Pandemic influenza A(H1N1) 2009 virus outbreak among boarding school pupils in Madagascar: compliance and adverse effects of prophylactic oseltamivir treatment.* Journal of Infection in Developing Countries, 2011. **5**(3): p. 156-62.
37. Lessler, J., et al., *Outbreak of 2009 pandemic influenza A (H1N1) at a New York City school.* New England Journal of Medicine, 2009. **361**(27): p. 2628-36.
38. Dorigatti, I., et al., *A new approach to characterising infectious disease transmission dynamics from sentinel surveillance: Application to the Italian 2009-2010 A/H1N1 influenza pandemic.* Epidemics, 2012. **4**(1): p. 9-21.
39. Freiesleben de Blasio, B., B.G. Iversen, and G. Tomba, *Effect of vaccines and antivirals during the major 2009 a(H1N1) pandemic wave in norway - and the influence of vaccination timing.* PLoS ONE, 2012. **7**(1).

40. Kara, E.O., et al., *Absenteeism in schools during the 2009 influenza A(H1N1) pandemic: a useful tool for early detection of influenza activity in the community?* Epidemiology & Infection, 2012. **140**(7): p. 1328-36.
41. Lau, E.H., et al., *Situational awareness of influenza activity based on multiple streams of surveillance data using multivariate dynamic linear model.* PLoS ONE [Electronic Resource], 2012. **7**(5): p. e38346.
42. Winslow, C.-E.A. and J.F. Rogers, *Statistics of the 1918 Epidemic of Influenza in Connecticut: With a consideration of the factors which influenced the prevalence of this disease in various communities* J Infect Dis, 1920. **26**(3): p. 185-216.
43. Effler, P.V., et al., *Household responses to pandemic (H1N1) 2009-related school closures, Perth, Western Australia.* Emerging Infectious Diseases, 2010. **16**(2): p. 205-11.
44. Briscoe, J.H., *The protective effect of influenza vaccine in a mixed influenza A and B epidemic in a boys' boarding school.* Journal of the Royal College of General Practitioners, 1977. **27**(166): p. 28-31.
45. Danis, K., et al., *Lessons from a pre-season influenza outbreak in a day school.* Communicable Disease & Public Health, 2004. **7**(3): p. 179-83.
46. Cashman, P., et al., *Pneumonia cluster in a boarding school--implications for influenza control.* Communicable Diseases Intelligence, 2007. **31**(3): p. 296-8.
47. Johnson, A.J., et al., *Household responses to school closure resulting from outbreak of influenza B, North Carolina.* Emerging Infectious Diseases, 2008. **14**(7): p. 1024-30.
48. Smith, A., et al., *An outbreak of influenza A(H1N1)v in a boarding school in South East England, May-June 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(27): p. 9.
49. Health Protection Agency West Midlands H1N1v Investigation Team, *Preliminary descriptive epidemiology of a large school outbreak of influenza A(H1N1)v in the West Midlands, United Kingdom, May 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(27).
50. Guinard, A., et al., *Outbreak of influenza A(H1N1)v without travel history in a school in the Toulouse district, France, June 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(27).
51. Shimada, T., et al., *Epidemiology of influenza A(H1N1)v virus infection in Japan, May-June 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(24).
52. Miller, J.C., et al., *Student behavior during a school closure caused by pandemic influenza A/H1N1.* PLoS ONE [Electronic Resource], 2010. **5**(5): p. e10425.
53. Cauchemez, S., et al., *Role of social networks in shaping disease transmission during a community outbreak of 2009 H1N1 pandemic influenza.* Proceedings of the National Academy of Sciences of the United States of America, 2011. **108**(7): p. 2825-30.
54. Cohen, N.J., et al., *Respiratory illness in households of school-dismissed students during pandemic (H1N1) 2009.* Emerging Infectious Diseases, 2011. **17**(9): p. 1756-1757.
55. Graitcer, S.B., et al., *Effects of immunizing school children with 2009 influenza A (H1N1) monovalent vaccine on absenteeism among students and teachers in Maine.* Vaccine, 2012. **30**(32): p. 4835-4841.
56. Leung, Y.H., M.P. Li, and S.K. Chuang, *A school outbreak of pandemic (H1N1) 2009 infection: assessment of secondary household transmission and the protective role of oseltamivir.* Epidemiology & Infection, 2011. **139**(1): p. 41-4.
57. Loustalot, F., et al., *Household transmission of 2009 pandemic influenza A (H1N1) and nonpharmaceutical interventions among households of high school students in San Antonio, Texas.* Clinical Infectious Diseases, 2011. **52 Suppl 1**: p. S146-53.

58. Marchbanks, T.L., et al., *An outbreak of 2009 pandemic influenza A (H1N1) virus infection in an elementary school in Pennsylvania.* Clinical Infectious Diseases, 2011. **52 Suppl 1**: p. S154-60.
59. Monto, A.S., et al., *Modification of an outbreak of influenza in Tecumseh, Michigan by vaccination of schoolchildren.* Journal of Infectious Diseases, 1970. **122**(1-2): p. 16-25.
60. Fang, L.Q., et al., *Distribution and risk factors of 2009 pandemic influenza a (h1n1) in Mainland China.* American Journal of Epidemiology, 2012. **175**(9): p. 890-897.
61. Alonso, W.J., et al., *Seasonality of influenza in Brazil: a traveling wave from the Amazon to the subtropics.* Am J Epidemiol, 2007. **165**(12): p. 1434-42.
62. Armstrong, C. and R. Hopkins, *An epidemiological study of the 1920 epidemic of influenza in an isolated rural community.* Public Health Reports, 1921. **36**(29): p. 1671-1702.
63. Baker, M.G., et al., *Pandemic influenza A(H1N1)v in New Zealand: the experience from April to August 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(34).
64. Tinoco, Y., et al., *Preliminary population-based epidemiological and clinical data on 2009 pandemic H1N1 influenza A (pH1N1) from Lima, Peru.* Influenza Other Respi Viruses, 2009. **3**(6): p. 253-6.
65. Miller, D.L. and J.A. Lee, *Influenza in Britain 1967-68.* Journal of Hygiene, 1969. **67**: p. 559-572.
66. Paine, S., et al., *Transmissibility of 2009 pandemic influenza A(H1N1) in New Zealand: effective reproduction number and influence of age, ethnicity and importations.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2010. **15**(24).
67. Evans, B., et al., *Has estimation of numbers of cases of pandemic influenza H1N1 in England in 2009 provided a useful measure of the occurrence of disease?* Influenza and other Respiratory Viruses, 2011. **5**(6): p. e504-e512.
68. Cruz-Pacheco, G., et al., *Modelling of the influenza A(H1N1)v outbreak in Mexico City, April-May 2009, with control sanitary measures.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(26).
69. Caley, P., D.J. Philp, and K. McCracken, *Quantifying social distancing arising from pandemic influenza.* Journal of the Royal Society Interface, 2008. **5**(23): p. 631-9.
70. Bootsma, M.C. and N.M. Ferguson, *The effect of public health measures on the 1918 influenza pandemic in U.S. cities.* Proceedings of the National Academy of Sciences of the United States of America, 2007. **104**(18): p. 7588-93.
71. Merler, S., et al., *Determinants of the spatiotemporal dynamics of the 2009 H1N1 pandemic in europe: Implications for real-time modelling.* PLoS Computational Biology, 2011. **7**(9).
72. Baguelin, M., et al., *Vaccination against pandemic influenza A/H1N1v in England: A real-time economic evaluation.* Vaccine, 2010. **28**(12): p. 2370-2384.
73. Echevarria-Zuno, S., et al., *Infection and death from influenza A H1N1 virus in Mexico: a retrospective analysis.* The Lancet, 2009. **374**(9707): p. 2072-2079.
74. Engelhard, D., et al., *Increased extent of and risk factors for pandemic (H1N1) 2009 and seasonal infl uenza among children, Israel.* Emerging Infectious Diseases, 2011. **17**(9): p. 1740-1743.
75. Hatchett, R.J., C.E. Mecher, and M. Lipsitch, *Public health interventions and epidemic intensity during the 1918 influenza pandemic.* Proceedings of the National Academy of Sciences of the United States of America, 2007. **104**(18): p. 7582-7.
76. Wallensten, A., et al., *Compliance and side effects of prophylactic oseltamivir treatment in a school in South West England.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(30): p. 19285.

77. Wang, C., et al., *Epidemiological and clinical characteristics of the outbreak of 2009 pandemic influenza A (H1N1) at a middle school in Luoyang, China.* Public Health, 2012. **126**(4): p. 289-94.
78. *Human infection with new influenza A (H1N1) virus: clinical observations from a school-associated outbreak in Kobe, Japan, May 2009.* Weekly Epidemiological Record, 2009. **84**(24): p. 237-44.
79. Nishiura, H., et al., *Transmission potential of the new influenza A(H1N1) virus and its age-specificity in Japan.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(22): p. 4.
80. Gomez, J., et al., *Pandemic influenza in a southern hemisphere setting: the experience in Peru from May to September, 2009.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(42).
81. Hsueh, P.R., et al., *Pandemic (H1N1) 2009 vaccination and class suspensions after outbreaks, Taipei City, Taiwan.* Emerging Infectious Diseases, 2010. **16**(8): p. 1309-11.
82. Kao, C.L., et al., *Emerged HA and NA mutants of the pandemic influenza H1N1 viruses with increasing epidemiological significance in Taipei and Kaohsiung, Taiwan, 2009-10.* PloS one, 2012. **7**(2): p. e31162.
83. Uchida, M., et al., *Swine-origin influenza a outbreak 2009 at Shinshu University, Japan.* BMC Public Health, 2011. **11**: p. 79.
84. Markel, H., et al., *Nonpharmaceutical interventions implemented by US cities during the 1918-1919 influenza pandemic.* Journal of the American Medical Association, 2007. **298**(6): p. 644-654.
85. Lo, J.Y., et al., *Respiratory infections during SARS outbreak, Hong Kong, 2003.* Emerging Infectious Diseases, 2005. **11**(11): p. 1738-41.
86. Wu, J., et al., *Safety and effectiveness of a 2009 H1N1 vaccine in Beijing.* New England Journal of Medicine, 2010. **363**(25): p. 2416-2423.
87. France, A.M., et al., *Household transmission of 2009 influenza A (H1N1) virus after a school-based outbreak in New York City, April-May 2009.* Journal of Infectious Diseases, 2010. **201**(7): p. 984-92.
88. Poggensee, G., et al., *The first wave of pandemic influenza (H1N1) 2009 in Germany: From initiation to acceleration.* BMC Infectious Diseases, 2010. **10**(155).
89. Chuang, J.H., et al., *Nationwide surveillance of influenza during the pandemic (2009-10) and post-pandemic (2010-11) periods in Taiwan.* PLoS ONE, 2012. **7**(4).
90. Farley, T.A., et al., *The impact of influenza vaccination on respiratory illness at a boarding School.* Journal of American College Health, 1992. **41**(3): p. 127-131.
91. Sonoguchi, T., H. Naito, and M. Hara, *Cross-subtype protection in humans during sequential, overlapping, and/or concurrent epidemics caused by H3N2 and H1N1 influenza viruses.* Journal of Infectious Diseases, 1985. **151**(1): p. 81-88.
92. Davies, J.R., et al., *Prophylactic use of amantadine in a boarding school outbreak of influenza A.* Journal of the Royal College of General Practitioners, 1988. **38**(313): p. 346-8.
93. Jackson, C., et al., *School closures and student contact patterns.* Emerging Infectious Diseases, 2011. **17**(2): p. 245-7.
94. Davis, L.E., G.G. Caldwell, and R.E. Lynch, *Hong Kong influenza: The epidemiologic features of a high school family study analyzed and compared with a similar study during the 1957Asian influenza epidemic.* American Journal of Epidemiology, 1970. **92**(4): p. 520.
95. Miller, E., et al., *Incidence of 2009 pandemic influenza A H1N1 infection in England: a cross-sectional serological study.* Lancet, 2010. **375**(9720): p. 1100-8.
96. Berkman, B.E., *Mitigating pandemic influenza: the ethics of implementing a school closure policy.* Journal of Public Health Management & Practice, 2008. **14**(4): p. 372-8.

97. Sadique, M.Z., E.J. Adams, and W.J. Edmunds, *Estimating the costs of school closure for mitigating an influenza pandemic.* BMC Public Health, 2008. **8**: p. 135.
98. Smith, R.D., et al., *The economy-wide impact of pandemic influenza on the UK: a computable general equilibrium modelling experiment.* BMJ, 2009. **339**: p. b4571.
99. Hodge, J.G., Jr., *The legal landscape for school closures in response to pandemic flu or other public health threats.* Biosecurity & Bioterrorism, 2009. **7**(1): p. 45-50.
100. Brunyate, W.D.T., et al., *The early stages of the 1957 influenza epidemic in England and Wales in relation to the re-assembly of schools.* Mon Bull Minist Hlth Lab Serv, 1961. **20**(MAY): p. 88-92.
101. Dunn, F.L., et al., *Epdemiologic studies of asian influenza in a louisiana parish.* Amer, 1959. **J.Hyg. 70**(3): p. 351-371.
102. Chao, D.L., M.E. Halloran, and I.M. Longini, Jr., *School opening dates predict pandemic influenza A(H1N1) outbreaks in the United States.* J Infect Dis, 2010. **202**(6): p. 877-80.
103. Araz, O.M., et al., *Simulating school closure policies for cost effective pandemic decision making.* BMC Public Health, 2012. **12**(1): p. 449.
104. House, T., et al., *Modelling the impact of local reactive school closures on critical care provision during an influenza pandemic.* Proceedings of the Royal Society of London - Series B: Biological Sciences, 2011. **278**(1719): p. 2753-60.
105. Ferguson, N.M., et al., *Strategies for mitigating an influenza pandemic.* Nature, 2006. **442**(7101): p. 448-52.
106. Haber, M.J., et al., *Effectiveness of interventions to reduce contact rates during a simulated influenza pandemic.* Emerging Infectious Diseases, 2007. **13**(4): p. 581-9.
107. Carrat, F., et al., *A 'small-world-like' model for comparing interventions aimed at preventing and controlling influenza pandemics.* BMC Medicine, 2006. **4**: p. 26.
108. Glass, R.J., et al., *Targeted social distancing design for pandemic influenza.* Emerging Infectious Diseases, 2006. **12**(11): p. 1671-81.
109. Yasuda, H., N. Yoshizawa, and K. Suzuki, *Modeling on social spread from immunity.* Jpn J Infect Dis, 2005. **58**(6): p. S14-5.
110. Ciofi degli Atti, M.L., et al., *Mitigation measures for pandemic influenza in Italy: an individual based model considering different scenarios.* PLoS ONE [Electronic Resource], 2008. **3**(3): p. e1790.
111. Yasuda, H., et al., *Preparedness for the spread of influenza: prohibition of traffic, school closure, and vaccination of children in the commuter towns of Tokyo.* Journal of Urban Health, 2008. **85**(4): p. 619-35.
112. Kelso, J.K., G.J. Milne, and H. Kelly, *Simulation suggests that rapid activation of social distancing can arrest epidemic development due to a novel strain of influenza.* BMC Public Health, 2009. **9**: p. 117.
113. Yasuda, H. and K. Suzuki, *Measures against transmission of pandemic H1N1 influenza in Japan in 2009: simulation model.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(44).
114. Davey, V.J., et al., *Effective, robust design of community mitigation for pandemic influenza: a systematic examination of proposed US guidance.* PLoS ONE [Electronic Resource], 2008. **3**(7): p. e2606.
115. Rizzo, C., et al., *Scenarios of diffusion and control of an influenza pandemic in Italy.* Epidemiology & Infection, 2008. **136**(12): p. 1650-7.
116. Vynnycky, E. and W.J. Edmunds, *Analyses of the 1957 (Asian) influenza pandemic in the United Kingdom and the impact of school closures.* Epidemiology & Infection, 2008. **136**(2): p. 166-79.
117. Glass, K. and B. Barnes, *How much would closing schools reduce transmission during an influenza pandemic?* Epidemiology, 2007. **18**(5): p. 623-8.
118. Lee, B.Y., et al., *Simulating school closure strategies to mitigate an influenza epidemic.* Journal of Public Health Management & Practice, 2010. **16**(3): p. 252-61.

119. Elveback, L.R., et al., *An influenza simulation model for immunization studies.* American Journal of Epidemiology, 1976. **103**(2): p. 152-65.
120. Germann, T.C., et al., *Mitigation strategies for pandemic influenza in the United States.* Proceedings of the National Academy of Sciences of the United States of America, 2006. **103**(15): p. 5935-40.
121. Davey, V.J. and R.J. Glass, *Rescinding community mitigation strategies in an influenza pandemic.* Emerging Infectious Diseases, 2008. **14**(3): p. 365-72.
122. Barrett, C., et al., *Economic and social impact of influenza mitigation strategies by demographic class.* Epidemics, 2011. **3**(1): p. 19-31.
123. Andradottir, S., et al., *Reactive strategies for containing developing outbreaks of pandemic influenza.* BMC Public Health, 2011. **11 Suppl 1**: p. S1.
124. Milne, G.J., et al., *A small community model for the transmission of infectious diseases: comparison of school closure as an intervention in individual-based models of an influenza pandemic.* PLoS ONE [Electronic Resource], 2008. **3**(12): p. e4005.
125. Perlroth, D.J., et al., *Health outcomes and costs of community mitigation strategies for an influenza pandemic in the United States.* Clinical Infectious Diseases, 2010. **50**(2): p. 165-74.
126. Roberts, M.G., et al., *A model for the spread and control of pandemic influenza in an isolated geographical region.* Journal of the Royal Society Interface, 2007. **4**(13): p. 325-30.
127. Bolton, K.J., et al., *Likely effectiveness of pharmaceutical and non-pharmaceutical interventions for mitigating influenza virus transmission in Mongolia.* Bulletin of the World Health Organization, 2012. **90**(4): p. 264-71.
128. Chao, D.L., et al., *FluTE, a publicly available stochastic influenza epidemic simulation model.* PLoS Computational Biology, 2010. **6**(1): p. e1000656.
129. Halder, N., J.K. Kelso, and G.J. Milne, *Analysis of the effectiveness of interventions used during the 2009 A/H1N1 influenza pandemic.* BMC Public Health, 2010. **10**: p. 168.
130. Halder, N., J.K. Kelso, and G.J. Milne, *Cost-effective strategies for mitigating a future influenza pandemic with H1N1 2009 characteristics.* PLoS ONE [Electronic Resource], 2011. **6**(7): p. e22087.
131. Halder, N., J.K. Kelso, and G.J. Milne, *Developing guidelines for school closure interventions to be used during a future influenza pandemic.* BMC Infectious Diseases, 2010. **10**: p. 221.
132. Zhang, T., et al., *Temporal factors in school closure policy for mitigating the spread of influenza.* Journal of Public Health Policy, 2011. **32**(2): p. 180-97.
133. Zhang, T., et al., *Evaluating temporal factors in combined interventions of workforce shift and school closure for mitigating the spread of influenza.* PLoS ONE [Electronic Resource], 2012. **7**(3): p. e32203.
134. Yang, Y., P.M. Atkinson, and D. Ettema, *Analysis of CDC social control measures using an agent-based simulation of an influenza epidemic in a city.* BMC Infectious Diseases, 2011. **11**: p. 199.
135. Mao, L., *Evaluating the combined effectiveness of influenza control strategies and human preventive behavior.* PLoS ONE [Electronic Resource], 2011. **6**(10): p. e24706.
136. Chao, D.L., et al., *Planning for the control of pandemic influenza A (H1N1) in Los Angeles County and the United States.* American Journal of Epidemiology, 2011. **173**(10): p. 1121-1130.
137. Morimoto, T. and H. Ishikawa, *Assessment of intervention strategies against a novel influenza epidemic using an individual-based model.* Environmental Health and Preventive Medicine, 2010. **15**(3): p. 151-161.
138. Sypsa, V. and A. Hatzakis, *School closure is currently the main strategy to mitigate influenza A(H1N1)v: a modeling study.* Euro Surveillance: Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(24).

139. Ferguson, N.M., et al., *Strategies for containing an emerging influenza pandemic in Southeast Asia.* Nature, 2005. **437**(7056): p. 209-14.
140. Timpka, T., et al., *Population-based simulations of influenza pandemics: validity and significance for public health policy.* Bulletin of the World Health Organization, 2009. **87**(4): p. 305-11.
141. Sander, B., et al., *Economic Evaluation of Influenza Pandemic Mitigation Strategies in the United States Using a Stochastic Microsimulation Transmission Model.* Value Health, 2009. **12**(2): p. 226-233.
142. Halloran, M.E., et al., *Modeling targeted layered containment of an influenza pandemic in the United States.* Proceedings of the National Academy of Sciences of the United States of America, 2008. **105**(12): p. 4639-44.
143. Lee, V.J., D.C. Lye, and A. Wilder-Smith, *Combination strategies for pandemic influenza response - a systematic review of mathematical modeling studies.* BMC Medicine, 2009. **7**: p. 76.
144. Eames, K.T., N.L. Tilston, and W.J. Edmunds, *The impact of school holidays on the social mixing patterns of school children.* Epidemics, 2011. **3**(2): p. 103-8.
145. Mossong, J., et al., *Social contacts and mixing patterns relevant to the spread of infectious diseases.* PLoS Medicine, 2008. **5**(3): p. 0381-0391.
146. Mikolajczyk, R.T., et al., *Social contacts of school children and the transmission of respiratory-spread pathogens.* Epidemiology & Infection, 2008. **136**(6): p. 813-22.
147. Hens, N., et al., *Mining social mixing patterns for infectious disease models based on a two-day population survey in Belgium.* BMC Infectious Diseases, 2009. **9**: p. 5.
148. Grilli, E.A., M.J. Anderson, and T.W. Hoskins, *Concurrent outbreaks of influenza and parvovirus B19 in a boys' boarding school.* Epidemiology and Infection, 1989. **103**(2): p. 359-369.
149. Olson, J.G., *School absenteeism during an outbread of B/Hong Kong/5/72-like influenze virus in Taipei, Taiwan.* Southeast Asian Journal of Tropical Medicine & Public Health, 1980. **11**(4): p. 429-34.
150. Cheng, C.K.Y., et al., *Electronic school absenteeism monitoring and influenza surveillance, Hong Kong.* Emerging Infectious Diseases, 2012. **18**(5): p. 885-887.
151. Shaw, C., M. McLean, and J. McKenzie, *Other surveillance reports: influenza-like illness in Wellington schools 2005.* New Zealand Public Health Surveillance Report, 2006. **4**(2): p. 4-6.
152. Leonida, D.D.J., *Morbidity patterns reflected in a school health program during an influenza epidemic season.* Illinois Medical Journal, 1970. **137**(3): p. 262-264.
153. Glass, R.I., et al., *Community-wide surveillance of influenza after outbreaks due to H3N2 (A/Victoria/75 and A/Texas/77) and H1N1 (A/USSR/77) influenza viruses, Mercer County, New Jersey, 1978.* Journal of Infectious Diseases, 1978. **138**(5): p. 703-6.
154. Louie, J.K., et al., *Creating a Model Program for Influenza Surveillance in California. Results from the 2005-2006 Influenza Season.* American Journal of Preventive Medicine, 2007. **33**(4): p. 353-357.
155. Smith, S., et al., *Early spread of the 2009 infuenza A(H1N1) pandemic in the United Kingdom - use of local syndromic data, May-August 2009.* Eurosurveillance, 2011. **16**(3).
156. Van Gageldonk-Lafeber, A.B., et al., *The relative clinical impact of 2009 pandemic influenza A (H1N1) in the community compared to seasonal influenza in the Netherlands was most marked among 5-14year olds.* Influenza and other Respiratory Viruses, 2011. **5**(6): p. e513-e520.
157. Chieochansin, T., et al., *Novel H1N1 2009 influenza virus infection in Bangkok, Thailand:Effects of school closures.* Asian Biomedicine, 2009. **3**(5): p. 469-475.
158. Cowling, B.J., et al., *The effective reproduction number of pandemic influenza: Prospective estimation.* Epidemiology, 2010. **21**(6): p. 842-846.
159. Hall, R.J., et al., *Pandemic influenza A(H1N1)v viruses currently circulating in New Zealand are sensitive to oseltamivir.* Euro Surveillance: Bulletin Europeen sur les

Maladies Transmissibles = European Communicable Disease Bulletin, 2009. **14**(30): p. 19282.

160. Stern, A.M. and H. Markel, *What Mexico taught the world about pandemic influenza preparedness and community mitigation strategies.* JAMA, 2009. **302**(11): p. 1221-2.
161. Lajous, M., et al., *Mobile messaging as surveillance tool during pandemic (H1N1) 2009, Mexico.* Emerging Infectious Diseases, 2010. **16**(9): p. 1488-9.
162. Janjua, N.Z., et al., *Seasonal influenza vaccine and increased risk of pandemic A/H1N1-related illness: First detection of the association in British Columbia, Canada.* Clinical Infectious Diseases, 2010. **51**(9): p. 1017-1027.
163. Janusz, K.B., et al., *Influenza-like illness in a community surrounding a school-based outbreak of 2009 pandemic influenza A (H1N1) virus-Chicago, Illinois, 2009.* Clinical Infectious Diseases, 2011. **52 Suppl 1**: p. S94-101.
164. Herrera-Valdez, M.A., M. Cruz-Aponte, and C. Castillo-Chavez, *Multiple outbreaks for the same pandemic: Local transportation and social distancing explain the different "Waves" of A-H1N1PDM cases observed in Mexico during 2009.* Mathematical Biosciences and Engineering, 2011. **8**(1): p. 21-48.
165. Jordan, E.O., D.B. Redd, and E.B. Fink, *Influenza in three Chicago groups.* Public Health Reports, 1919. **34**(28): p. 1528-1545.
166. Mniszewski, S.M., et al., *Pandemic simulation of antivirals plus school closures: buying time until strain-specific vaccine is available.* Computational and Mathematical Organization Theory, 2008. **14**(3): p. 209-221.
167. Longini, I.M., Jr., et al., *Containing pandemic influenza with antiviral agents.* American Journal of Epidemiology, 2004. **159**(7): p. 623-33.
168. Longini, I.M., Jr., et al., *Containing pandemic influenza at the source.* Science, 2005. **309**(5737): p. 1083-7.
169. Kelso, J.K., N. Halder, and G.J. Milne, *The impact of case diagnosis coverage and diagnosis delays on the effectiveness of antiviral strategies in mitigating pandemic influenza A/H1N1 2009.* PLoS ONE [Electronic Resource], 2010. **5**(11): p. e13797.
170. Fine, P.E. and J.A. Clarkson, *Measles in England and Wales--I: An analysis of factors underlying seasonal patterns.* International Journal of Epidemiology, 1982. **11**(1): p. 5-14.
171. Ghosh, S. and J. Heffernan, *Influenza pandemic waves under various mitigation strategies with 2009 H1N1 as a case study.* PLoS ONE [Electronic Resource], 2010. **5**(12): p. e14307.

Appendix 1: Search strategy for identifying epidemiological studies of the effects of school closures on incidence / transmission of influenza

1. influenza.mp. or exp Influenza, Human/
2. exp Incidence/
3. exp Morbidity/
4. exp Sentinel Surveillance/ or exp Population Surveillance/
5. exp Disease Transmission, Horizontal/ or exp Acute Disease/ or exp Disease Notification/ or exp Disease Outbreaks/ or exp Communicable Disease Control/ or exp Disease/ or exp Disease Transmission/
6. (incidence or rate or morbidity or mortality or surveillance or risk or illness or death or case* or disease or infect*).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
7. (infect* or communicable or contagio*).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
8. exp Infection/
9. exp Communicable Diseases/ or exp Communicable Disease Control/ or exp Communicable Diseases, Emerging/
10. 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9
11. ((school adj5 clos*) or (nurser* adj5 clos*) or (daycare adj5 clos*) or (day adj care adj5 clos*)).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
12. exp Schools/
13. 11 or 12
14. 1 and 10 and 13

Appendix 2: Search strategy for identifying modelling studies of the effects of school closure on incidence / transmission of influenza

1. ((school adj5 clos*) or (nurser* adj5 clos*) or (kindergarten adj5 clos*) or (daycare adj5 clos*) or (day adj care adj5 clos*) or (preschool* adj5 clos*) or (pre-school* adj5 clos*) or (child* adj5 home) or (schoolchild* adj5 home) or (teenage* adj5 home) or (preschool* adj5 home) or (pre-school* adj5 home) or (adolescent adj5 home) or (social adj5 distanc*)).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
2. exp Schools/
3. 1 or 2
4. (infect* or communicable or contagio*).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
5. (mortality or (attack adj5 rate) or morbidity or incidence).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
6. exp Incidence/
7. exp Infection/
8. exp Communicable Diseases/ or exp Communicable Disease Control/ or exp Communicable Diseases, Emerging/
9. exp Disease outbreaks/
10. 4 or 5 or 6 or 7 or 8 or 9
11. (model* or (mathematical adj5 model*) or (transmission adj5 model*) or (simulation adj5 model*) or (statistical adj5 model*) or (epidemi* adj5 model*) or (dynamic* adj5 model*) or (computer adj5 model*) or simulation).mp. [mp=title, original title, abstract, name of substance word, subject heading word, unique identifier]
12. exp Models, Theoretical/
13. exp Models, Statistical/
14. exp Computer simulation/
15. 11 or 12 or 13 or 14
16. 3 and 10 and 15

Appendix 3: Quality assessment for epidemiological studies

Study population

Is the study population clearly defined, e.g. schoolchildren only or general population?
Is the study population representative of the wider population?
Is the study population large enough to draw conclusions?

School closure

Were schools closed before the epidemic had peaked?
Which schools were closed (e.g. primary versus secondary schools)?

Case ascertainment

Were cases ascertained in the same way throughout the outbreak?
Was the outcome measure specific?
Was the outcome measure sensitive?

Analysis

Does the analysis go beyond a description of the epidemic curve in relation to the closing of schools?
Are the results considered in terms of transmission dynamics as well as incidence?
Was any apparent effect reversed when schools were reopened?
Are age-specific results presented?
Are possible confounders considered?
Are confidence intervals and/or statistical tests presented?
Is there a comparison group, and is this group appropriate?

Appendix 4: Guidelines for comparing modelling studies

Baseline model parameters

Is the model age-stratified?

If so, which age groups are used?

Are contact patterns assumed to be age-dependent?

Are infection parameters (latent and infectious periods and/or serial interval, R_0) stated or estimated appropriately?

Are these values consistent with those which occurred in previous pandemics or epidemics?

Does the model attempt to describe transmission in different settings (e.g. the home, school, community)?

Baseline model validation

Has the model been fitted to data from previous pandemics / epidemics?

If so, what data have been used for this?

Does the model replicate previous pandemics / epidemics?

Modelling of school closure as a specific intervention

Are school closures explicitly modelled?

Assumptions about the effects of school closures on contact patterns

What effects are school closures assumed to have on contact between children and between children and adults?

Are these effects estimated from data or assumed?

If assumed, are the assumptions clearly stated?

Are these assumptions based on empirical data?

Are school closures studied as a single intervention or in combination with other strategies, e.g. antiviral use, vaccination?

Are nurseries and / or workplaces closed as well as schools?

Reporting of results

Are the results presented in terms of:

- Changes in overall and/or age-specific cumulative attack rate
- Changes in overall and/or age-specific peak attack rate
- Changes in duration of the epidemic
- Changes in time to peak of the epidemic
- Changes in the effective reproduction number

- Impact on mortality

Sensitivity analyses

Are the effects of using different values of R_0 explored?

Are different assumptions about baseline mixing patterns explored?

Are different assumptions about the effects of school closures on mixing patterns explored? (For example, are alternative changes in contact patterns, for example increased attendance of children at out-of-school activities, considered?)

Are the effects of varying the threshold / timing / duration of closures explored?

Is there an estimate of the conditions required (e.g. threshold for intervention, changes in contact patterns) to negate the effects of school closure?

Appendix 5: Studies of the effects of school closures on seasonal influenza outbreaks

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Europe							
Briscoe (1977) [44]	Outbreak report / estimate of vaccine efficacy	1231 boys at Eton College, 1976 (79% of whom were vaccinated). Age of pupils not stated but the school currently takes boys aged 13-18.	Planned half term holiday	Friday 20 to Monday 23 February	Epidemic began in late January, first wave peaked 6 February, second wave peaked 17 February.	Clinical influenza (n = 372); confirmed as influenza A in 6/8 swabbed cases and influenza B in 1/8.	One case on day before break, ~12 cases on following day. ~1-4 cases/day for rest of study period. Hypothesised that closure curtailed the epidemics in individual school houses. 15/26 houses had no further cases after the break.
Davies et al (1988) [92]	Non-controlled intervention study of prophylactic amantadine	859 boys aged 11-18 years at Christ's Hospital boarding school, 1986	Planned half term holiday	Friday 21 to Monday 24 February	Epidemic began in early February, prophylaxis began on 5 February coinciding with the peak	Clinical influenza (n = 181); confirmed as influenza A H3N2 in majority of cases	0-3 cases/day in five days preceding closure; 12 cases over 4-day closure period. Daily case numbers immediately following re-opening similar to those before closure.
Grilli et al (1989) [148]	Outbreak report	675 boys aged 11-18 years at Christ's Hospital boarding school, 1985	Planned mid-term break	22-24 February	Epidemic began in late January and appeared to peak (at ~19 cases) 4 days before closure	ILI in pupils reporting to school infirmary (n = 206), the majority of which were confirmed as influenza.	4-5 cases on each of the 2 days before closure; 15 cases occurred during closure (no daily breakdown is provided). ~0-6 cases occurred per day over the month following reopening.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Danis et al (2004) [45]	Outbreak report	802 pupils at boys' secondary school (age 11-18 years), Ireland, 2003	Response to outbreak	Whole school closed 4-11 September; 6th class sent home earlier (date not stated)	Whole school closure from day after peak of outbreak	ILI in absentees ascertained through telephone and questionnaire surveys (n = 107); confirmed as influenza in 12/15 cases	Peak incidence ~45 cases on day before closure; 18 cases on first day of closure and continuing decline thereafter. Only 2 cases after re-opening (although there was no active case finding at this point). Little evidence of community spread after the school outbreak.
Miller and Lee (1969) [65]	Outbreak report	England and Scotland (all ages), November 1967 – February 1968	Planned Christmas holiday	Two weeks, all schools	Schools closed during the growth phase of the epidemic in most age groups	Age-specific rates of influenza reported by general practitioners	Rates in 0-4, 15-44, 45-64 and ≥65 year olds peaked during the second week of closure, rates in 5-14 year olds were in decline at this point. Following reopening, increases occurred in the 0-4 and especially 5-14 year age groups.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cauchemez et al (2008) [7]	Statistical / transmission modelling analysis based on fitting to surveillance data	French national sentinel surveillance system, 1985-2006 (covering all ages, over 60 epidemic periods and from ~1% of practicing GPs)	Routine school holidays	Approx 2 weeks in each of December – January, February – March, March-April. Timing varies by 1-2 weeks in the 2-3 holiday zones.	Varied between epidemics	Rates of influenza-like illness reported through sentinel GPs	Estimated that holidays resulted in a 20-29% (median 24%) decrease in rate of transmission to children, without affecting contacts made by adults; this translated to a reduction in the attack rate of 16-18% overall (14-17% for adults, 18-21% for children)

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Kara et al (2012) [40]	Descriptive study comparing of school absenteeism data and other surveillance sources.	Children aged 4-18 years attending 373 schools in Birmingham, Sept 2006 – July 2009 (absenteeism data); Children aged 4-18 years with postcodes in Birmingham (NHS Direct data, Sept 2006 – July 2009); Children aged 5-14 years attending GPs in the West Midlands region (RCGP data, Sept 2006 – July 2009).	Planned holidays	1, 2 or 5 weeks (depending on holiday),	Varied by year	School absenteeism; calls to NHS Direct for cold / flu and fever; ILI consultation rates.	Percentage of children absent often lower following summer holiday than before, no clear relationship with other holidays. Percentage of NHS Direct calls due to fever often decreased during holidays. Relationship between consultation data and school holidays varied.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Asia							
Olson et al (1980) [149]	Outbreak report	Grades 1-6 (2831 students) of Girls Teachers' Colleges Primary School, Taipei and grades 1-6 (650 students) of Taipei American School , Taiwan, September 1975 – May 1976. Ages of students not stated.	Planned holiday during virologically confirmed community influenza outbreak	Six weeks (Girls Teachers' Colleges Primary School); 3 weeks (Taipei American School)	Relationship with influenza circulation unclear, but likely to be late in the outbreak. Absenteeism at Girls Teachers' Colleges Primary School peaked two weeks before closure; absenteeism at Taipei American School had not exceeded the epidemic threshold at the time of closure.	School absenteeism (all cause)	Girls Teachers' Colleges Primary School: absenteeism declined from ~1.65 absences per child-day in the week before closure to ~0.7 absences per child-day (only slightly above expected absenteeism of 0.65) in the week following re-opening. Taipei American School: absenteeism very similar before and after closure

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Sonoguchi et al (1985)[91]	Cohort study of the extent of cross-protection between influenza subtypes	173 children (of 245 enrolled) aged 13-14 at a middle school in Tokyo; 347 children (of 374 enrolled) at a high school in Kumamoto prefecture, Japan. >90% vaccination coverage at each school.	Planned winter holiday (middle school); response to high levels of absenteeism (high school)	Two weeks (middle school); 3 days (high school)	Middle school: case numbers were fairly constant at <5/day during the week before closure. High school: epidemic appeared to be in decline when school closed but case numbers increased on reopening.	Absenteeism while the schools were open; serious, confirmed influenza A infection during closure periods.	Middle school: case numbers remained low at 0-2 per day during closure. High school: case numbers declined from 16 on the day before closure to 13, 5 and 0 on the three days of closure, rebounding to 21 on the day of reopening.
Fujii et al (2002)[34]	Descriptive study of surveillance data	Children aged 4-14 years attending 36 sentinel surveillance in Japan, 1999-2000	Planned holiday	2 weeks	Case numbers began to increase from week 50 of 1999; schools closed week 52 and week 1.	Medically attended clinical ILI	191 cases in week before closure, declining by 38% to 118 cases during the first week of closure. Incidence increased to 173 cases during the second week of closure and an epidemic followed when schools reopened.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Heymann et al (2004)[8]	Ecological before-and-after comparison	All 6-12 year old children (n = 186094) registered with one of the four national healthcare insurance schemes, Israel, 2000	National teachers' strike affecting ~80% of 6-12 year old children[9] coinciding with influenza outbreak	2 weeks (16-28 January 2000), elementary schools nationwide. Ultra-orthodox schools, preschools and high schools remained open.	Outbreak began in last week of December 1999; schools closed 16-28 January 2000.	Medically attended / diagnosed respiratory tract infections (MARI); All physician visits; All outpatient clinic visits; All emergency department visits; hospitalisations; medication purchases (antibiotics, antipyretics, cold and cough medicines).	MARI: number of cases decreased by 42% and 27% during closure period and following fortnight respectively, compared to the fortnight before the closure.* Physician visits: rate ratios 0.78 and 0.88* No effect on hospital admissions.
Lo et al (2005)[85]	Ecological before-and-after comparison	Respiratory specimens (all ages) processed by Government Virus Unit, Hong Kong, 1998-2003	Reaction to SARS outbreaks; other social distancing and hygiene measure also implemented	Not stated, but general community control measures were in effect at least in April – June 2003	Not clear	Proportion of respiratory specimens positive for influenza	Monthly proportions positive were 58-88% lower in April – June 2003 than the average for the corresponding months of 1998-2003, but the difference with specific years was variable (e.g. little difference with the low influenza years of 1999 and 2000).

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cowling et al (2008) [12]	Ecological before-and-after comparison with modelling analysis	Hong Kong population (all ages), 2008	Reactive closure for 1 week in response to 3 influenza deaths in children, followed by scheduled 1 week Easter break.	2 weeks (including Easter break) – all primary schools, special schools, kindergartens and day nurseries.	Outbreak began in January and peaked in February; schools closed 13 March.	Influenza A and B isolations from surveillance data as proportion of all specimens (for children and adults separately); sentinel ILI consultation rates; influenza hospital admission rates in children aged <5 years; estimates of effective reproduction number.	Continued decrease in already declining incidence measures; no apparent meaningful change in effective reproduction number.
Heymann et al (2009) [9]	Ecological before-and-after comparison, with comparison to years not affected by atypical school closure	Individuals aged ≥6 years registered with a specific healthcare service provider in Israel, 1998-2002	Teachers' strike affecting ~80% of children, coinciding with influenza outbreak in 2000; Hanukah holidays in all years.	8 days each year for Hanukah holiday; 2 week closure (16-28 January 2000) of elementary schools nationwide, excluding ultra-orthodox, preschools and high schools.	Closure due to strike as Heymann (2004) [8]; timing of Hanukah holidays in relation to respective epidemics not clear.	Ratio of number of clinic visits for ILI to number for non-respiratory illness, in 6-12 year olds and individuals aged over 12 (calculated separately for those living with and without 6-12 year olds).	Decrease in ratio of 15% for 6-12 year olds associated with the strike; decreases in adults were not statistically significant. In some years, there was evidence of a reduction in the ratio for adults and/or children associated with the Hanukah holidays.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cheng et al (2012) [150]	Descriptive study comparing school absenteeism data against other surveillance sources.	18-62 schools (varying over time) in Hong Kong, March 2008 – June 2011.	One reactive closure (analysed in detail in Wu et al [13] and discussed below); 7 planned school holidays.	All participating schools; length of holidays varied.	Varied, but typically in early stages of outbreak.	ILI-specific absenteeism; ILI consultation rates from sentinel surveillance (all ages); influenza virus isolations (all ages).	No clear and consistent relationship between school closure and any of the outcome measures.
Chuang et al (2012) [89]	Outbreak report	General population of Taiwan, week 26 of 2009 to week 13 of 2011.	Planned holiday (Lunar New Year).	One week; all schools.	In between end of circulation of H3N2 and beginning of circulation of H1N1 / influenza B in 2010/11.	Emergency room and outpatient visits for ILI; hospitalised confirmed influenza cases with severe complications; influenza-associated deaths (2010/11 only).	No apparent effect on ER and outpatient visits in 2010/11. No clear effect on incidence of hospitalised severe cases. Numbers of influenza-associated deaths were higher during the week of school closure than in the preceding or following week.
Lau et al (2012) [41]	Descriptive study integrating multiple influenza surveillance data sources.	General population of Hong Kong, February 2008 – December 2009 (some datasets begin earlier but school holiday dates are not available).	Planned holidays (reactive closures during one seasonal [12] outbreak and the 2009 pandemic [13] are described in detail in other studies).	Duration unclear but variable; all schools in Hong Kong. (School closure periods inferred from gaps in absenteeism data.)	Close to peak or at beginning of epidemic.	ILI at public outpatient clinics and private GPs; school absenteeism; laboratory isolations; inferred influenza activity from integrating these data sources.	No clear relationship between school closures and any of the indicators (however, graphs do not allow easy assessment of this).

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Australasia							
Cashman et al (2007) [46]	Outbreak report	Secondary boarding / day school (age of pupils not stated), New South Wales, Australia, August 2006	Planned closure coinciding with outbreak of ILI and pneumonia	Four days	Unclear, but closure appears to have occurred late in outbreak	Presentations to sick bay with respiratory illness (n not stated). Influenza A H3N2 isolated from 5 students	Respiratory presentations decreased following closure, returning to baseline within 7 days (no further quantitative information provided).
Shaw et al (2006) [151]	Outbreak report	Single school in Wellington, New Zealand, May-June 2005 – 350 pupils in years 1-8.	One closure in response to high levels of absenteeism; later closure for a “holiday weekend”	Two closures of 4 days each, including weekends in both cases	Peak absenteeism occurred on the day before the first closure; epidemic was generally declining before the second closure	School absenteeism (all causes)	For both closures, absenteeism was lower on reopening than before the closure.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Americas							
Leonida (1970) [152]	Outbreak report	Five elementary schools (student population 2314) and three high schools (student population 8012) in Skokie, Illinois, September 1967 – April 1968	Winter holiday	One week at the end of November and two weeks at the end of December; all schools in the sample	First closure 2 weeks before peak in elementary schools and 2 weeks after peak in high schools; second closure 2 weeks after peak in elementary schools and 6 weeks after peak in high schools.	School absenteeism due to ILI.	First closure had no clear effect on the increase in absenteeism at the elementary schools or the decline in the high schools. Absenteeism continued to decline in both elementary and high schools during the second closure; no apparent increase on reopening.
Glass et al (1978) [153]	Outbreak report	Mercer County, New Jersey, USA, November 1977 – March 1978	Planned Christmas holiday	One week (public schools) or two weeks (residential schools)	Around peak of outbreak	Absenteeism from 6 public schools, work absenteeism, febrile illnesses in nursing homes, admissions to three residential school infirmaries, emergency room visits, hospital admissions for acute respiratory disease, P&I deaths, viral isolates	School absenteeism was lower after the holiday than before and gradually increased, reaching a plateau at a level slightly higher than before the closure. Emergency room visits and hospital admissions peaked during the closure week and viral isolates the week before.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Farley et al (1992) [90]	Outbreak report / estimate of vaccine efficacy	Boarding school, Connecticut (989 pupils in grades 9-12), January – April 1989	Planned holiday	Three weeks	Epidemic appeared to be largely over by the time of the holiday (there were ~8 cases in the week before closure; the peak had occurred 5 weeks previously)	Admission to school infirmary with fever or respiratory symptoms (n ~135)	Number of admissions remained low (≤8 per week) after reopening.
Louie et al (2007) [154]	Descriptive study of several surveillance systems during one influenza season	California, week 40 of 2005 to week 15 of 2006	Planned winter holiday	Two weeks; presumably all schools	ILI peaked week before closure; laboratory isolations appeared to be increasing when schools were closed.	ILI reported through sentinel surveillance system (expressed as the proportion of all visits that were for ILI); number of laboratory-confirmed influenza from sentinel laboratories.	ILI declined throughout school closure and remained at low levels following reopening; laboratory-confirmed infections declined slightly in the first week of closure, then increased before declining after schools reopened.
Johnson et al (2008) [47]	Outbreak report focussing on effects of closure on families	355 children enrolled in all 9 public elementary, middle and high schools in Yancey County, North Carolina, USA, 2006.	Closure for operational reasons, due to high levels of staff absenteeism largely attributed to ILI.	10 days (2 – 12 November) - all 9 schools in the county.	First reported onset (in study sample) 20 October, epidemic peak 1 November, schools closed 2 November.	Parentally-reported ILI (n = 123) ascertained through telephone survey	Incidence decreased from peak of 8 cases the day before closure to 5 cases on the first day of closure, and continued to decline thereafter.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Rodriguez et al (2009) [11]	Cohort study comparing schools which cancelled their winter break to those which did not	265 elementary, middle, high and “other” schools which closed and 205 which did not, King County, Washington, February – March 2007	Planned holiday closure coinciding with influenza outbreak	1 week, including middle, high and other public and private schools	Closure immediately following epidemic peak	School absenteeism (all causes)	No evidence of a difference in absenteeism following the break between schools that closed and those that did not.
Wheeler et al (2010) [26]	Ecological before-and-after comparison covering fortnights before, during and after school closure in 4 influenza seasons.	General population of Arizona, 2004/05 – 2007/08 influenza seasons.	Planned winter holidays	2 weeks, all schools in the state	Peak occurred at least 2 weeks after reopening in 3 of the 4 seasons; peak coincided with the second week of closure in the remaining season.	Influenza laboratory reports 2004/05 to 2007/08 (n = 833 in school-aged children, 4036 in other age groups); influenza hospitalisations 2004/05 to 2006/07 (n = 885 in school-aged children, 4512 in other age groups).	For school-aged children, incidence never significantly increased during the two weeks of closure compared to the preceding two weeks; incidence in the two weeks following reopening either increased (2 seasons), declined (1 season) or was unchanged compared to the weeks of closure. For other age groups, incidence consistently increased during the closure period; changes on reopening were inconsistent.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Alonso et al (2012) [18]	Ecological study of relationship between number of isolations of various respiratory viruses (including influenza) and exposures including school terms.	Children aged 1 month to 16 years with ARI symptoms, attending a public teaching hospital in Fortaleza, Brazil, 2001-2008.	Planned holidays.	Not stated.	Not stated, presumably varied between years.	Laboratory-confirmed influenza.	Correlation coefficient between school terms and number of influenza reports always <0.2 (assessed with lags of 0-11 weeks).

* Recalculated from data provided in paper

Appendix 6: Studies of the effects of school closures on pandemic influenza

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Europe							
Smith et al (2009) [48]	Outbreak report	1307 pupils aged 13-18 at a boarding school in SE England, May – June 2009	Scheduled break extended in response to outbreak; prophylactic oseltamivir also used	11 days (4 day scheduled break extended by 7 days). Some pupils returned ~1 week earlier for exams	Closed around time of epidemic peak	Clinical ILI in pupils attending school healthcare facilities 1-27 May; laboratory-confirmed H1N1v after 27 May (n = 102 including both clinical and confirmed cases)	Apparent decline in cases in pupils following closure; no information on other age groups
HPA West Midlands H1N1v Investigation Team (2009) [49]	Outbreak report	479 primary and nursery school pupils (aged 4-12), plus 84 staff, at a school in Birmingham, England, May 2009	Scheduled break extended in response to outbreak; prophylactic oseltamivir also used	11 days (9 day scheduled break extended by 2 days)	After epidemic peak	Laboratory confirmed H1N1v (n = 64)	Case numbers in pupils and staff declined following closure (e.g. from 8 cases on the day of closure to 5 on each of the two following days). No further cases following re-opening. Limited information on illness in other groups.
Wallensten et al (2009) [76]	Outbreak report	248 Year 7 pupils at a school in SW England (93% of the year group, aged 11-12 years), April – May 2009	Response to outbreak; prophylactic oseltamivir also used	10 days	Unclear	Prevalence of self-reported ILI during the week before closure, the closure week, and the following week	5, 11 and 10 children had symptoms compatible with the case definition in the week before, during and after closure, respectively. Absenteeism was almost identical in the weeks before and after closure. No information on illness in other age groups.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Calatayud et al (2010) [28]	Outbreak report	1177 pupils (year groups Reception to 13), plus staff, at a school in London, May 2009	Response to outbreak (preceded by closure for Easter several weeks previously); use of prophylactic oseltamivir	3 days of Easter holiday remained after onset of first possible case; reactive closure lasted 9 days (including 2 weekends).	One possible case occurred 3 days before the end of the Easter closure and did not attend school while symptomatic; no further cases occurred until the main outbreak began ~7-10 days after this possible case. Reactive closure occurred the day following the peak (6 cases).	Virologically confirmed or possible (symptomatic without combined nose and throat swab but pending serological results) H1N1 infection	Cases continued to occur at 3-4 cases / day for 4 days following reactive closure. On the 5th and 6th days, there were 0 and 1 cases, respectively, and no cases subsequent to this.
Hens et al (2012) [24]	Further modelling analysis of outbreak reported in Calatayud et al [28]	As Calatayud et al [28]	As Calatayud et al [28]	As Calatayud et al [28]	As Calatayud et al [28]	Effective reproduction number estimated from reconstructed transmission trees (based on symptomatic cases with laboratory confirmation)	R_n was estimated as 2.51 (95% CI 2.11 – 3.00) before the outbreak was detected, 1.33 (95% CI 1.11 – 1.56) after the outbreak was detected but before school closure, and 0.43 (95% CI 0.35 – 0.52) after school closure.
Strong et al (2010) [29]	Outbreak report, focussing on use of antivirals	297 pupils (aged 7-12 years) and 58 staff at a primary school in Sheffield, June 2009	Response to outbreak; oseltamivir used for treatment and prophylaxis	One week	Epidemic peaked 3 days before closure.	Self-reported ILI (n = 61)	Incidence continued to decline while school was closed; no data presented for period after reopening.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Baguelin et al (2010) [72]	Study of cost-effectiveness of vaccination based on a modified SEIR transmission model and economic analysis; includes incidence data spanning term time and holiday periods.	England & Wales population, June – October 2009.	Planned summer holiday.	~ 6 weeks, all schools nationally.	Closure coincided with peak of the first wave.	Health Protection Agency estimates of numbers of infections, rescaled (multiplied by 10) to reflect under-reporting.	Incidence declined throughout the period of school closure and increased after schools reopened, producing a second wave of infection.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Kara et al (2012) [40]	Descriptive study comparing school absenteeism data and other surveillance sources.	Children aged 4-18 years attending 373 schools in Birmingham, (absenteeism data); Children aged 4-18 years with postcodes in Birmingham (NHS Direct data); Children aged 5-14 years attending GPs in the West Midlands region (RCGP data); Children aged 4-18 years living in Birmingham Local Authority (laboratory data).	Planned holidays	1 week half terms; 5 week summer holiday.	Percentage of specimens positive for H1N1had increased markedly the week before half term; laboratory testing was no longer done for all cases by the time of the summer holiday but absenteeism was generally declining by this time.	School absenteeism; calls to NHS Direct for cold / flu and fever; ILI consultation rates; pandemic H1N1 laboratory reports.	Percentage of specimens positive for H1N1 declined during half term. No clear effect of half term or summer holiday on absenteeism. Percentage of NHS Direct calls due to cold / flu increased during half term and decreased during summer holiday; percentage due to fever increased slightly during summer holiday but not half term. ILI consultation rates appeared unaffected by half term, initially declined and then increased during summer holiday.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Guinard et al (2009) [50]	Outbreak report	30 students (aged 11-12 years) and 18 staff from one affected class, at a secondary school in Toulouse, France, June 2009	Reactive closure in response to outbreak; some use of prophylactic oseltamivir	7 days	At apparent end of epidemic	Probable H1N1v infection with or without laboratory confirmation (n = 17 with known date of onset, plus 3 without)	No further cases in pupils or their contacts following closure, but epidemic appeared to be over before the school was closed.
Carrillo-Santisteve et al (2010) [33]	Outbreak report	Two primary schools (360 and 293 aged 6-11 years), a nursery school (253 children aged 3-6 years) and a daycare school (unknown number of children aged 3 months to 3 years), Paris, June 2009; the four schools shared some facilities.	Response to outbreak which began in one of the primary schools; close contacts were given prophylactic oseltamivir.	9 days (including 2 weekends), one of the primary schools and the nursery school (these schools accounted for 59/66 cases in pupils)	Officially closed on day of peak, but weekend began two days previously.	Confirmed and probable influenza cases in children attending the closed schools and their families and friends who consulted influenza outpatient clinic (n = 81)	Incidence in the closed primary school peaked on the 3rd day of closure (12 cases) and fell to 2 cases on each of the two following days; no further cases occurred. Incidence in the closed nursery school increased through the first 3 days of closure to a peak of 6 cases, then declined to 0-1 cases per day for 4 days; no further cases occurred after this. Cases in families and friends of the schoolchildren (n = 15) occurred only during the period of school closures.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Poggensee et al (2010) [88]	Outbreak report	General population of Germany, April – November 2009	Planned holiday.	Duration not stated; school closure is described using the weekly "vacation density" (the percentage of the population living in states in which schools were closed) as the timing of the holiday varied between states	Vacation density peaked in the early stages of the outbreak, while the practice index was below the seasonal threshold and not increasing markedly. A second increase in the vacation density occurred while the practice index was increasing linearly.	Acute respiratory illness reported through sentinel surveillance system, used to calculate a "practice index" (defined as "the relative deviation of observed consultations for ARI divided by all consultations in the same week and set into relation to the background value of this ratio in weeks without influenza virus circulation")	Practice index remained fairly constant throughout the main school holiday period and increased only when the vacation density was declining; the second increase in the vacation density was followed by a brief plateau in the practice index.
Birrell et al (2011) [19]	Transmission modelling analysis (SEIR model) based on GP consultation and viral positivity data	General population of London, UK, May – December 2009	Planned holidays	Six week summer holiday and two half terms of one week each (in May and October); all schools in London closed.	As Baguelin et al [72] (closure coincided with peak of the first wave)	Influenza-like illness recorded through GP sentinel surveillance scheme together with serological and virological data; parameters estimated included the reduction in contact rates associated with school holidays.	Both peaks in the two waves of consultations coincided with a school holiday. The summer holiday was estimated to reduce contacts amongst 5-14 year olds by 72% and the half term holiday by 48%; no effects were apparent in other age groups.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Evans et al (2011) [67]	Descriptive study of estimated number of ILI cases due to pandemic H1N1 based on GP consultation data, helpline usage, virological swabbing and assumptions about the proportion of infections resulting in healthcare seeking.	General population of England, June – December 2009.	Planned holiday.	Six week summer holiday affecting all schools nationally.	As Baguelin et al [72] (closure coincided with peak of the first wave)	Estimate numbers of ILI cases due to pandemic H1N1, by age and region.	Estimated incidence declined during the school holiday and increased following reopening, in all regions and in all age groups except for the <1 and ≥65 year olds (among whom estimated case numbers were low).
Smith et al (2011) [155]	Descriptive study of telephone helpline (NHS Direct) and GP consultation data	General UK population, May – August 2009; results also presented separately for London and West Midlands regions.	Planned school summer holiday (late July to early September).	Approximately six weeks; all schools nationally.	First week of school closure coincided with national peak in NHS Direct calls but occurred after the peak for London and the West Midlands. Consultation data peaked in the first week of closure nationally and before closure in London.	Weekly percentage of calls to NHS Direct that were classified as cold / flu. Weekly GP consultation rates for ILI.	Both indices continued to decline during closure; no data presented after schools reopened.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Eames et al (2012) [22]	Mathematical model utilising contact data reported through an online survey, including presentation of empirical incidence data.	Incidence data: general population of UK; Contact data: 3338 participants in an online survey, July – December 2009.	Planned summer and half term holidays.	Approximately 6 weeks (summer holiday) and 1 week (autumn half term).	Based on other UK papers [72], start of summer holiday coincided with peak in incidence.	Estimated influenza incidence based on reported cases and scaled up according to two different estimates of the proportion of infected individuals seeking medical care (similar data to other UK studies [19, 72]).	Incidence declined during summer holiday and increased afterwards; transmission model found that this could be explained by self-reported changes in contact patterns during holidays compared to term time.
Balasegaram et al (2012) [32]	Descriptive study of early outbreak data in relation to area-level measures of deprivation.	General population of London, UK, April – June 2009.	Planned half term holiday.	Presumably all schools in area; 1 week.	19 H1 positive cases reported in total in 6 weeks before closure, 38 in week of closure with continuing increases in the following 4 weeks.	Number of tests and percentage positive for influenza A and H1 (not age-stratified). Age-stratified risks also provided but case definition unclear.	Percentage positive increased during half term and continued to increase over subsequent week. No clear change in age-stratified risks during half term; increase in risk began the following week.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Flasche et al (2011) [23]	Ecological study analysing the relationship between the estimated effective reproduction number for H1N1 pandemic influenza in 12 European countries (in 2009) and several explanatory variables, including school holiday dates	General populations in Belgium, Bulgaria, England, France, Germany, Italy, Luxembourg, Netherlands, Portugal, Romania, Slovakia and Spain, April – October 2009. School holidays occurred during the study period in all countries except Bulgaria, England and France.	Planned holidays.	Varied by country.	Varied by country, but typically early in the respective outbreaks.	Effective reproduction number estimated from numbers of laboratory-confirmed pandemic H1N1 infections.	No evidence found of a relationship between the effective reproduction number and the start of school holidays.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
van Gageldonk-Lafeber et al (2011) [156]	Outbreak report; comparison of pandemic and seasonal ILI consultation data.	General population of the Netherlands, and residents of nursing homes considered separately, October – December 2009	Planned holidays	One week; all schools nationally although timing varied by region.	In north and central regions, schools closed two weeks after the epidemic threshold consultation rate was exceeded nationally; in the south, schools closed one week later.	GP consultation rates for ILI (age-stratified); ILI rates in nursing home residents; age-specific H1N1 hospital admission rates.	Possible reduction in incidence, or slowing of epidemic growth, among 0-4, 5-9, 10-14 and 15-19 year olds; epidemic continued to grow after schools reopened. No apparent effect of school closure on ILI in nursing home residents or hospital admissions.
Merler et al (2011) [71]	Modelling analysis (stochastic individual-based model) of factors influencing spatiotemporal spread of pandemic H1N1 in Europe	General population of 37 European countries, May – December 2009	Mainly planned holidays; some reactive closures.	Varied by country; summer holidays typically lasted 6-12 weeks and autumn holidays approximately 2 days to 2 weeks.	Varied by country.	Predicted numbers of infections for comparison with ILI surveillance data.	The model reproduced the observed incidence patterns in the different countries most closely when country-specific school holidays were included and contact rates in the population were allowed to change during holidays. (Transmission was assumed to be eliminated in schools and increased by a factor of 1.4 in the community during holidays.)

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Petrovic et al (2011) [35]	Outbreak report / analysis of risk factors for death in hospitalised cases.	Catchment population (n = 102,723) of general practices participating in sentinel surveillance, Vojvodina, Serbia, September 2009 – April 2010.	Response to outbreak.	All schools in Vojvodina; a closure lasting one week was followed six weeks later by a three week closure.	First closure coincided with first peak in ILI consultations in all ages and 5-14 year olds, but after the peak in 0-4 year olds. Second closure occurred after peak.	ILI consultation rates, overall and by age group.	ILI consultation rates declined following first closure and increased after schools reopened, particularly in 5-14 and 15-64 year olds. Rates were already declining when schools closed for second time and continued to do so during closure; possible slight increase after reopening.
Dorigatti et al (2012) [38]	SEIR model investigating possible reasons for age distribution of infection during 2009 pandemic and incorporating uncertainty in surveillance data (including graphical display of surveillance data).	Catchment population of general practices participating in sentinel surveillance, Italy, September 2009 – February 2010.	Planned Christmas holidays.	All schools nationally; approximately 2 weeks.	Closure began six weeks after peak.	ILI consultation rates overall and for 0-4, 5-14, 15-64 and ≥65 year olds.	No clear effect in any age group.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Freiesleben de Blasio et al (2012) [39]	SEIR model assessing effectiveness of vaccination and antivirals, including graphical display of surveillance data.	Catchment population of general practices participating in sentinel surveillance, Norway, May 2009 – February 2010.	Planned holiday.	Two weeks, apparently all schools nationally.	Five weeks after the peak of the first wave.	ILI (all ages)	Incidence changed little during the two week closure but increased when schools re-opened.
Asia							
WHO (2009) [78]	Outbreak report, primarily reporting clinical aspects of infection	School pupils in Hyogo Prefecture and Osaka Prefecture, Japan, May 2009	Response to school-associated outbreak	7 days, >1400 schools closed but unclear whether this represents all schools in the two prefectures	Unclear	School absenteeism	No increase in school absenteeism upon reopening of schools (no quantification of absence levels given)
Nishiura et al (2009) [79], Shimada et al (2009) [51]	Outbreak reports (both report essentially the same data with slightly different analyses)	General Japanese population, May – June 2009	Response to outbreak associated primarily with schools; some use of prophylactic oseltamivir [78]	7 days (possibly more in some cases), all schools in Hyogo and Osaka prefectures (preceded by weekend closure)	First confirmed cases had disease onset on 9 May, weekend / closure began 16 May	Laboratory-confirmed H1N1 influenza (restricted to indigenously-acquired cases in [79] (n = 361[79] or 392 [51])	Case numbers peaked at ~70 cases on the second day of the weekend, then declined throughout week of closure; no obvious resurgence on reopening

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Kawaguchi et al (2009) [30]	Outbreak report (subset of the data used in the two studies above)	Schools in Osaka Prefecture, Japan, May 2009; ages of affected students not stated.	Response to outbreak; some use of prophylactic oseltamivir in families of cases	1 week (preceded by a weekend), all 270 high schools and 526 junior high schools, and most nurseries, primary schools, colleges and universities, in Osaka prefecture	Epidemic peaked on second day of closure (i.e. at the weekend)	Confirmed H1N1 infection (n = 156)	Peak of 30 cases on second day of weekend and declined throughout closure period; no resurgence after re-opening
Chieochansin et al (2009) [157]	Outbreak report	General population of Bangkok, June – July 2009	Public holiday followed later by closure in response to outbreak	Public holiday lasted 1 week; schools were subsequently closed for 1 week and tutorial schools for 2 weeks	Public holiday occurred during peak week. Closure of schools and tutorial schools began during the following week.	Laboratory confirmed pandemic H1N1 influenza	Incidence declined throughout period of closure.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Wu et al (2010) [13]	Age-structured SIR model fitted to data on laboratory-confirmed cases during the 2009 pandemic in Hong Kong, used to estimate reporting rates and the reduction in within age group transmission resulting from school closures	General population of Hong Kong, June – August 2009	Response to outbreak, followed by planned school holiday	All primary schools, kindergartens, childcare centres and special schools closed for ~1 month immediately prior to the summer holiday (duration of holiday not stated). Secondary schools with ≥1 case closed for 14 days, all secondary schools closed for summer holiday at same time as primary schools	At start of growth phase of first wave, which peaked around the 10th day of closure. School holidays started at the beginning of the growth phase of a second wave.	Laboratory-confirmed pandemic influenza cases, proportion of these in different age groups (0-12 years, 13-17 years and ≥18 years) and percentage reduction in within age group transmission resulting from school closures.	First wave continued to grow during school closure, followed by second wave beginning around the start of the school holidays. Following school closure, numbers of cases in 0-12 year olds remained low but the proportion of cases in this age group increased slightly, while that in 13-17 year olds decreased. School closure was estimated to reduce transmission between children of the relevant age group by 70% (95% CI 64-75%), corresponding to an overall reduction in transmission of ~25%.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cowling et al (2010) [158]	Modelling analysis which estimates daily effective reproduction numbers using data on laboratory-confirmed cases and on hospitalisations, together with information on the serial interval.	General population of Hong Kong, May – October 2009	Response to outbreak, followed by planned school holiday	All primary schools, kindergartens, childcare centres and special schools closed for ~1 month immediately prior to the summer holiday (duration of holiday not stated). Secondary schools with ≥1 case closed for 14 days, all secondary schools closed for summer holiday at same time as primary schools	At start of growth phase of first wave, which peaked around the 10th day of closure. School holidays started at the beginning of the growth phase of a second wave.	Laboratory-confirmed pandemic influenza cases and hospitalisations, used to estimate daily values of the effective reproduction number.	Effective reproduction number declined during initial days of closure, oscillated around 1 for the duration of the closure period, increased very slightly when schools reopened before declining again.
Hsueh et al (2010) [81]	Outbreak report	General population of Taipei City, Taiwan, June 2009 – January 2010	Response to outbreak	Individual classes suspended for at least 5 days if >2 students had confirmed infection within 3 days.	Timing for individual schools not presented; number of class suspensions generally increased with the number of hospitalisations.	Hospitalisations with pandemic H1N1.	Number of class suspensions generally followed the number of hospitalisations.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Wu et al (2010) [86]	Cohort study assessing vaccine effectiveness amongst children attending public primary and middle schools and participating in a national celebration parade. Only unvaccinated children are considered in this review.	95244 vaccinated participants in a national celebration parade, Beijing; of these, 25037 vaccinated schoolchildren were compared to 244091 unvaccinated schoolchildren.	Planned national holiday	1 week, all schools nationally.	Schools closed as cumulative incidence in unvaccinated students began to plateau	Laboratory confirmed H1N1 infection	Cumulative incidence in unvaccinated children increased very slightly during the school closure (from ~220 to ~260 per 100,000); rate of increase in cumulative incidence increased ~1 week after schools reopened. Cumulative incidence in vaccinated students remained relatively constant before, during and after school closure.
Huai et al (2010) [27]	Outbreak report	Primary school (1314 pupils) in Dongguan City, Guangdong Province, China, June 2009	Response to outbreak, shortly followed by planned summer break.	Affected primary school closed 19-28 June; all schools in the town closed 22-28 June, Planned summer break began on 2 July.	Affected school closed on day of peak.	Confirmed or suspected cases in children attending affected school (n = 105); limited data on cases in the community are also included.	Epidemic in schoolchildren peaked at 30 cases on the first day of closure, declining to 11 the following day. No further cases occurred between the last two days of closure and the subsequent closure for the holiday.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Engelhard et al (2011) [74]	Outbreak report	Children aged <18 years enrolled with one health maintenance organisation in Israel, June 2009 – April 2010.	Two separate planned holidays.	Summer holiday lasted 9 weeks, autumn holiday lasted 5 weeks.	Summer holiday occurred close to beginning of first wave; autumn holiday close to beginning of second.	Rate of ILI (fever with one or more of cough, coryza, sore throat, myalgia) visits to community health clinics.	ILI rate peaked and decliend during summer holiday, began to increase when schools reopened and reached a second peak during the autumn holiday before declining again. A third wave occurred after the autumn holiday.
Leung et al (2011) [56]	Outbreak report / analysis of household secondary attack rates and effect of oseltamivir.	511 children attending a secondary school in Hong Kong and their 205 household contacts, June 2009. No cases occurred amongst the 153 school staff.	Response to outbreak	Two weeks, coinciding with closure of all schools in Hong Kong.	Three days after peak.	Laboratory-confirmed pandemic H1N1 in schoolchildren or household contacts.	Incidence increased during first two days of closure and subsequently remained very low; last case occurred one week before reopening.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cheng et al (2012) [150]	Descriptive study comparing school absenteeism data against other surveillance sources.	50 schools in Hong Kong, 2009-10	Reactive closure (analysed in detail in Wu et al [13]).	All participating schools. Primary schools, kindergartens, childcare centres and special schools closed for ~1 month immediately prior to the summer holiday (duration of holiday not stated). Secondary schools with ≥1 case closed for 14 days, all secondary schools closed for summer holiday at same time as primary schools [13].	Based on Wu, at start of growth phase of first wave, which peaked around the 10th day of closure. School holidays started at the beginning of the growth phase of a second wave [13].	ILI-specific absenteeism; ILI consultation rates from sentinel surveillance (all ages); influenza virus isolations (all ages).	ILI absenteeism considerably on reopening than before closure.ILI consultations and virus isolations initially gradually increased during closure but dipped towards the end of the closure period; both continued to increase after schools reopened.
Chuang et al (2012) [89]	Outbreak report	General population of Taiwan, week 26 of 2009 to week 13 of 2011.	Planned holiday (Lunar New Year).	One week; all schools.	At end of H1N1 outbreak	Emergency room and outpatient visits for ILI; hospitalised confirmed influenza cases with severe complications;	ER and outpatient visits increased during closure. No clear effect on incidence of hospitalised severe cases.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Lau et al (2012) [41]	Descriptive study integrating multiple influenza surveillance data sources.	General population of Hong Kong, June – December 2009.	Planned holidays (reactive closures during one seasonal [12] outbreak and the 2009 pandemic [13] are described in detail in other studies).	As in Wu et al [13]: All primary schools, kindergartens, childcare centres and special schools closed for ~1 month immediately prior to the summer holiday (duration of holiday not stated). Secondary schools with ≥1 case closed for 14 days, all secondary schools closed for summer holiday at same time as primary schools.	As in Wu et al [13]: At start of growth phase of first wave, which peaked around the 10th day of closure. School holidays started at the beginning of the growth phase of a second wave.	ILI at public outpatient clinics and private GPs; school absenteeism; laboratory isolations; inferred influenza activity from integrating these data sources.	Apparent dips in laboratory isolations following closure. Other data sources showed no clear effect (although graphs are not designed to allow this to be easily seen).

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Uchida et al (2011) [83]	Descriptive cohort study of pandemic H1N1	2318 schoolchildren, 11424 university students and 3344 staff members associated with Shinshu University Organisation, August 2009 – March 2010	Planned breaks and reactive closures.	Planned summer holiday affected all schools for approximately one month; winter holiday for 3 weeks; reactive school and class closures varied for individual schools.	Summer holiday occurred before outbreak began; winter holiday occurred while incidence was declining. Timing of reactive closures in relation to incidence in individual schools unclear.	"Influenza-like symptoms and diagnosed with confirmed, probable or suspected swine flu at hospital or clinics."	Incidence continued to decline during the winter holiday. Incidence also appeared to declined during reactive school and class closures, but this is unclear as data are not presented for individual schools.
Fang et al (2012) [60]	Ecological study analysing factors influencing spatial and temporal spread of pandemic influenza.	General population of mainland China, May – December 2009.	Planned holiday.	One week; all schools nationally.	Incidence began to decline three days before closure but rebounded following the reopening of schools.	Suspected and laboratory-confirmed pandemic influenza; percentage difference in the incidence of pandemic influenza during school closure compared to period when schools were open (adjusted for temperature, relative humidity, population density and density of medical facilities).	Marked decline in incidence beginning three days before closure. Poisson regression estimated a 36.4% (95% CI 35.5-37.2%) reduction in incidence during school closures (after adjustment).

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Ahmed et al (2012) [31]	Outbreak report	General population of Abu Dhabi Emirate, May – August 2009	Planned holiday	Ten weeks; all schools nationally	Very close to beginning of outbreak: first case was reported in week 21, second case in week 24 and schools closed in week 26.	Laboratory-confirmed H1N1 infection.	Incidence continued to increase during the first four weeks of closure, then remained relatively constant for a further three weeks before increasing. Data do not extend to the end of the holiday period.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Uchida et al (2012) [14]	Cohort analysis of outbreak data (more detailed analysis of data presented in Uchida et al [83]).	Children attending two elementary and two junior high schools in Nagano Prefecture Japan (one elementary and one junior high school in each of two districts).	Response to outbreak	Either individual classes (more than one could be closed at any one time and classes could close more than once) or whole school; duration at class level varied from one to eight consecutive days.	First closure in each school occurred before substantial case numbers had been reported.	Confirmed, probable or suspected H1N1 influenza in children attending these schools, diagnosed by a physician and reported to the school by parents (with dates of onset up to 7 days after resumption of classes). Unclear whether ascertainment operated in the same way while classes / schools were closed. Also used Poisson regression to assess relationship between closure duration, school closure and class grade and the number of cases recorded in the 7 days after resumption of classes.	In one elementary school and one junior high school, incidence appeared to decrease following school, but not class, closure; in the others, incidence appeared relatively unaffected by sequential class closure. Rate ratio relating closure duration to number of cases after reopening estimated as 0.70 (95% CI 0.56 – 0.88, p = 0.002); this is discussed in the main text.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Wang et al (2012) [77]	Outbreak report	2586 of 2768 pupils and 158 of 184 staff at a middle school in Luoyang, China, August – September 2009.	Response to outbreak	15 days.	First day of closure coincided with peak of outbreak.	Confirmed or suspected pandemic H1N1 influenza.	Number of cases peaked on the first day of closure and declined over the following four days. 0-1 cases occurred on each of the following four days; data for the remainder of the school closure period and after re-opening are not presented.
Yu et al (2012) [25]	Statistical / modelling analysis of outbreak data	General population of China, April – August 2009.	Planned summer holiday; planned National Day Holiday	8 weeks / 1 week	Summer holiday occurred early in outbreak, when number of cases rarely exceeded 50/day. National Day Holiday occurred shortly after the peak of the first wave.	Confirmed cases of pandemic H1N1 influenza; estimates of effective reproduction number based on the growth rate before, during and after National Day Holiday (excluding summer holiday period); doubling time during summer holiday and month after schools reopened.	Summer holiday had no apparent effect on the epidemic (based on visual assessment of epidemic curve or doubling time). Weekly case numbers were lower during the National Day Holiday and the following week than the week preceding the holiday, although daily case numbers increased before the end of the break. Effective reproduction number was estimated as 1.25 (95% credible interval 1.22 -1.28) before, 0.79 (95% CrI 0.69 -0.90) during and 1.23 (95% CrI 1.15 -1.33) after the National Day Holiday.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Kao et al (2012) [82]	Descriptive analysis of viral isolates and epidemic curve.	General population of Taipei and Kaohsiung, Taiwan, June 2009 – October 2010.	Response to outbreak	Individual classes closed if >2 students were ILI cases within three days of each other, for a period of 3 days (i.e. number of classes closed varies over time). Duration of policy implementation assumed to as in Hsueh et al [81].	Policy introduced ~9 weeks after detection of first community case.	Percentage of specimens positive for pandemic H1N1 in hospitalised patients.	In Taipei, percentage positive generally (but not consistently) increased following the introduction of the closure policy. In Kaohsiung, percentage positive fluctuated without a consistent trend.
Africa							
Rajatonirina et al (2011) [36]	Outbreak report / analysis of oseltamivir compliance and side effects.	132 boarders at a school in Antananarivo, Madagascar, October – November 2009.	Planned holiday	2 weeks	After main phase of epidemic.	At least one influenza-like symptom (n = 56 with known onset date).	Epidemic appeared to be largely over when the school closed; sporadic cases continued to occur during closure period.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Australasia							
Caley et al (2008) [69]	Transmission modelling analysis of hospitalisation and mortality data	Sydney, 1919 (all ages)	Response to outbreak; combined with other social distancing interventions	~4.5 weeks initially; schools reopened for ~3 weeks and then closed for a further ~2 months.	Initial closure occurred as first cases were detected; second closure occurred during exponential growth phase of epidemic.	Estimated reduction in "behaviours resulting in disease transmission."	Transmission reduced by 38% during period of school closure.
Baker et al (2009) [63]	Outbreak report	New Zealand population, April – August 2009 (all ages)	Planned national holiday during national outbreak; some use of prophylactic antivirals during containment phase [159]	2 weeks, apparently all schools nationally	Depending on indicator, closure coincided with peak, preceded it by 1 week, or followed it by 1-3 weeks	Cases reported through notifiable disease surveillance system (n = 3179); hospitalisations amongst these cases (n = 972); ICU influenza admissions (n = 106); GP consultation rates (two surveillance systems)	Notifications, hospitalisations and ICU admissions began to decline during second week of closure. GP consultation rates for 5-14 year olds increased following re-opening (in one of the systems only).
Effler et al (2010) [43]	Outbreak report focussing on children's activities during closure and the effects of closure on families	Three schools in Perth, Western Australia, May – July 2009; ages of affected pupils not stated. Data available for 233 of 402 students.	Response to outbreak	1 week; one school closed completely and two closed only affected year groups	Confirmed cases in individuals attending the three schools peaked two days before closure	Confirmed pandemic H1N1 infection	Confirmed cases peaked at ~9/day two days before closure, subsequently a maximum of 1 case / day occurred.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Paine et al (2010) [66]	Outbreak report and modelling analysis	New Zealand population, April – November 2009 (all ages)	Planned national holiday during national outbreak; some use of prophylactic antivirals during containment phase [159]	2 weeks, all schools nationally	~4 days before peak.	Cases reported through notifiable disease surveillance system (n = 3254), used to estimate daily values of the effective reproduction number	Case numbers peaked and declined during holiday, no consistent increase when schools reopened. Effective reproduction number was declining before school closure and continued to decrease during the holiday, appeared to increase slightly and reach a plateau after schools reopened.
Americas							
Cruz-Pacheco et al (2009) [68]	SIR transmission model used to estimate contact rates, based on estimated values of R_0 before and after introduction of control measures	Mexico City, April – May 2009 (all ages)	Response to outbreak; no use of antivirals	~2.5 weeks, all schools in Mexico City.	Epidemic had been growing exponentially for ~1 week when schools were closed	Number of confirmed (n = 1752) or probable (n = 6114) cases; estimated daily reproduction number (R_t)	Incidence increased initially to peak of ~400 probable and 150 confirmed cases/day on second and third days of closure, then declined gradually over the closure period. R_t declined from ~1.6 before and during the closure, crossing 1 within 2 days of closure and remaining <1 thereafter.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Echevarria-Zuno et al (2009) [73]	Outbreak report	National population of Mexico, April – July 2009	Response to outbreak; no mention of antiviral prophylaxis	Approx two weeks; entire education system (including nurseries and universities) initially in Mexico City and Mexico State from 23 April, then nationwide from 27 April [160]. Universities and high schools reopened 4-5 days before elementary schools [68].	Schools closed early in growth phase of epidemic.	ILI reported through active surveillance of inpatients and outpatients	Epidemic continued while schools were closed and peaked ~1 week after closure; increase in cases over three days after reopening of universities and high schools, but not following subsequent reopening of elementary schools.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Lajous et al (2010) [161]	Outbreak report	56,551 respondents to a text message survey, Mexico, April 2009	Both planned closure and a response to the outbreak	Planned holiday lasted 1 week; reactive closure lasted at least one week (schools were still closed at the end of the time period presented)	Planned closure occurred in the early stages of the outbreak before national surveillance indicated an increase in the number of cases but case numbers from survey data were declining. Reactive closure occurred during the increase in national case numbers.	ILI in survey respondents; suspected or confirmed H1N1 from national surveillance	Planned closure was followed by a slight decrease in case numbers reported through national surveillance, but this increased before schools reopened. National surveillance data peaked ~3 days after the reactive school closure and then declined through the rest of the closure period. Survey data were not obviously affected by school closure, although the proportion of reported cases which prevented respondents working declined during both closure periods.
Gomez et al (2009) [80]	Outbreak report	National population of Peru, May – September 2009	Appears to be reactive, but unclear; some use of prophylactic oseltamivir	3 weeks, all schools nationwide	One week after peak week	Number of pneumonia cases in 5-59 year olds in Lima and Callao; number of severe acute respiratory infections nationally	Pneumonia cases decreased from peak week ~130 cases following closure to ~40 cases and showed slight resurgence to just below 60 cases when schools re-opened; effect on other severe respiratory infections difficult to assess as date of closure is unclear.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Tinoco et al (2009) [64]	Prospective cohort study	1747 individuals in 343 randomly selected households, San Juan de Miraflores District, Lima, Peru, May – August 2009	Unclear	~3 weeks, presumably all schools	After peak	Influenza-like illness counts by causative organism (H1N1 or other); age-specific rates of confirmed H1N1v	Number of ILI cases (and confirmed H1N1) decreased throughout closure period, from 54 (39 H1N1) the preceding week to 29 (19), 12 (6) and 6 (3) in each subsequent week; rates of confirmed H1N1 reached zero in week following closure in all age groups except 50-59 year olds.
Lessler et al (2009) [37]	Outbreak report	1453 students (aged 14-19) and staff at a New York City high school, April – May 2009	Response to outbreak	9 days, one school	After peak	Confirmed H1N1 influenza or self-reported ILI	Incidence already declining when school was closed, continued to decline through closure period. No data presented for period following re-opening.
Miller et al (2010) [52]	Descriptive study of schoolchildren's behaviour during reactive school closure	Private girls' school in Boston, USA; 63 of 176 children in grades 5-8 and 188 of 240 in grades 9-12.	Response to outbreak / high levels of absenteeism	One week	4 days after peak	Fever in pupils with ILI, and absenteeism, in upper and lower school separately	Upper and lower schools each had one case of fever on the first day of closure and continued to have 0 or 1 case per day throughout the closure period; no apparent increase on reopening. Absenteeism in both schools was considerably higher before closure than after reopening.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Janjua et al (2010) [162]	Cohort study of households of children enrolled in any of the six schools in the community, telephone survey primarily aimed at conducting a case-control study of the effect of vaccination against seasonal influenza on risk of infection with pandemic H1N1.	Elementary school and surrounding community, British Colombia, Canada, April – May 2009.	Response to outbreak in one elementary school	9 days	Outbreak peaked on the first day of school closure	ILI (n = 92) in 1092 participants from households of children attending any school in the community	Daily number of cases declined during school closure (from 10 cases on the first day to 1 case on the final day), increasing to 5 cases on the day of reopening. Case numbers ranged from 0-3 per day for the remainder of the study period.
Marchbanks et al (2011) [58]	Outbreak report	388 of 456 pupils at an elementary school in Pennsylvania, USA, and 957 household contacts, May 2009.	Response to outbreak	7 days	ILI peaked two days before school closure.	ILI (93 pupils and 74 contacts): subjective fever with cough and / or sore throat.	Incidence increased on second day of closure and then declined; very slight increase on reopening (although absenteeism returned to normal). No cases occurredin the 4th grade during closure or after reopening.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Cauchemez et al (2011) [7]	More detailed modelling analysis of outbreak described in Marchbanks et al [58]	Same school as Marchbanks et al [58], but using data from 27 April to 30 May 2009 from 370 pupils and 899 household contacts.	As Marchbanks et al [58]	As Marchbanks et al [58]	ARI epidemic curve peaked 2 and 3 days before closure.	Acute respiratory infection (at least two of fever, cough, sore throat, runny nose) in children attending the affected school (stratified by grade) and their household contacts (stratified into adults and children).129 cases in pupils and 141 in household contacts.	Incidence increased on the second day of closure but then declined; slight increase on reopening. Statistical analysis found no evidence of an effect of closure on the transmission rate among pupils (30% reduction, 95% credible interval 62% decrease to 22% increase). Reproduction number was also similar (0.3) during the week of closure and the following week.
Janusz et al (2011) [163]	Outbreak report and community-based survey. Community survey collected data from 240 of 711 households approached (comprising 644 individuals).	A community associated with a school which experienced an outbreak, Chicago, USA, April – May 2009.	Response to outbreak.	7 days; one of the five elementary schools in the community closed.	Approximately one third of ILI cases reported through the survey had occurred before school closure (0-3 per day). Only 4 laboratory-confirmed cases had been reported to the Department of Health before closure.	ILI (fever with cough and / or sore throat, n = 37) in the survey; laboratory confirmed H1N1 infection reported to Chicago Department of Public Health (n = 43) based on date of specimen collection, although the peak based on date of onset occurred 3 days before closure.	In the community survey, maximum of 3 cases per day before and during closure; no increase when school reopened. None of the cases reported through this survey were linked to the affected school. Laboratory reports peaked on the first day of closure, generally declined during closure and remained low after reopening; however, testing recommendations changed on the second day of closure.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Cohen et al (2011) [54]	Outbreak report	Pupils at a school in Chicago which closed due to the outbreak, and their household contacts (170 households, of 609 eligible, provided data), April – May 2009.	Response to outbreak.	1 week.	Highest numbers of cases were reported on the two days before closure.	Acute respiratory illness (one or more of fever, cough, sore throat, rhinorrhoea or nasal congestion, n = 58).	Case numbers were lower on the first day of closure than on the two previous days, increased during closure and then declined. Few cases were reported after school reopened.
Loustalot et al (2011) [57]	Cross-sectional questionnaire survey / assessment of household secondary attack rate and use of non-pharmaceutical interventions.	668 households (2772 individuals) of 1716 approached, with children attending a closed high school in San Antonio, Texas, March – June 2009.	Response to outbreak	9 days	Peak occurred 8 days before school closure	ILI in household members reported by one adult household member, stratified into index cases (students attending the affected school, n = 78) and secondary cases (n = 21)	Incidence remained low during closure; no cases reported on the final four days of closure. 1-2 cases per day after school reopened.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Chowell et al (2011a) [21]	Epidemiological and modelling analysis of outbreak data	107 million individuals registered with a Mexican private medical system, April – December 2009	Response to outbreak, and a later planned summer holiday.	Reactive closure lasted from 24 April to 5 May; summer holiday lasted ~7 weeks; all schools nationally were closed.	Reactive closure occurred early in the first wave of the outbreak (together with other interventions); summer holiday followed a plateau in the number of confirmed cases.	Confirmed pandemic H1N1 cases or ratio of number of cases in students (aged 5-20 years) to number of cases in other age groups.	Reactive closure appeared to slow epidemic growth, which resumed when interventions were lifted. Incidence was reasonably constant in all ages during the summer holiday but declined amongst students; cases amongst students and others increased when schools reopened (as did the ratio of student to non-student cases).
Herrera-Valdez et al (2011) [164]	Modelling analysis, including estimation of change in contact rate during school closure period.	National population of Mexico, April – November 2009	One reactive closure and a subsequent planned holiday	Reactive closure lasted ~2 weeks; holiday lasted ~2 months.	Schools closed reactively early in growth phase; holiday started close to the peak of the second wave.	Confirmed pandemic H1N1 cases; model estimates of contact rate.	Confirmed cases occurred in three waves corresponding to closing and reopening of schools. Estimated contact rates appeared to be reduced by ~80% during school closure periods.
Chowell et al (2011b) [20]	Epidemiological / spatial analysis of outbreak data	General population of Peru, May – December 2009	Planned school holiday moved forward by two weeks	Three weeks, all schools in the country	After the peak in daily national data; same week as peak in weekly data stratified into students and others.	Confirmed pandemic H1N1 cases or ratio of number of cases in students (aged 5-20 years) to number of cases in other age groups.	Number of cases in whole population, students and others declined throughout closure period; no clear increase on reopening. Ratio of student to non-student cases had already peaked, but declined during closure and increased afterwards.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Briffault (2011) [15]	Ecological study comparing the average percentage of emergency department / outpatient visits associated with ILI in areas in which schools were in session to areas in which schools were closed.	General population in 21 areas of the USA	Planned holidays.	Duration varied between areas; study period includes 18 weeks during which schools in at least one area were on holiday and 5 weeks when schools in all areas were closed.	Difficult to assess; likely to have varied between areas and between schools within the same area.	Percentage of emergency department or outpatient visits associated with ILI. The mean of these was take for schools in session and those closed for holidays, for each week, and the mean over time compared between these two groups using the Mann-Whitney-Wilcoxon test.	Percentage of visits due to ILI was ~3.5% in schools which were in session compared to ~2.8% in schools which were closed for the holidays.
Graitcer et al (2012) [55]	Ecological study of effects of student vaccination coverage on student and staff absenteeism.	93 schools in Maine, USA, October 2009 – March 2010	Planned holidays	Closure for Thanksgiving lasted ~1 week; winter break lasted ~2 weeks; spring break lasted ~1 week.	Thanksgiving occurred 2 weeks after the peak; winter break occurred in the final stages of the outbreak; very few influenza isolates were reported by the time of the spring break.	Daily percentage of students absent; percentage of specimens submitted to public health laboratory which were influenza.	Absenteeism was lower after Thanksgiving break than before; slightly lower after winter break than before; and similar before and after spring break. Number of laboratory reports increased very slightly during week of Thanksgiving break and subsequently declined; winter break had no clear effect on number of reports.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Earn et al 2012 [10]	Age-structured SIR model fitted to outbreak data; transmission parameters were allowed to vary as a function of school closure and weather variables.	General population of Alberta, Calgary and Edmonton (Canada), all stratified into children aged 5-18 years and others, April 2009 – January 2010.	Planned holidays.	Approx 7 weeks; closure dates differed slightly by type of school (high, middle, elementary, junior kindergarten) and in Calgary compared to the rest of the province.	Near to beginning of first wave: number of cases appeared to be elevated for only 2 weeks before the first school closure.	Number of laboratory-confirmed infections; estimates of R_0 derived from this for school terms and holidays.	Number of specimens reached a plateau and then declined during school closure; this was most apparent in school-aged children but also affected the other age group. Best-fitting model included a reduction in transmission amongst children: the child-to-child basic reproduction number was reduced by 63% (95% CI 43-84%) in Calgary, 100% (95% CI 69-100%) in Edmonton and 86% (95% CI 70-100%) in Alberta.

Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Egger et al (2012) [17]	Ecological study comparing schools which met criteria for student dismissal, and did close, and those which met the criteria but did not close.	64 public schools which met dismissal criteria in New York City, May – June 2009, of which 24 closed and 40 did not.	Response to outbreak.	Duration varied by school; mode was 5 days.	"Average" epidemic curve produced by pooling data from all schools (stratified by whether or not they closed) and aligning by time in relation to closure (day 0 = day dismissal criteria were met) showed peaks on day 0 in both schools which closed and those which did not.	Percentage of student body presenting to school medical room with ILI, averaged over schools stratified by whether or not they closed. Parameter estimates and model predictions from negative binomial regression assessing the relationship between closure and ILI counts.	Average percentage reporting with ILI declined in the days immediately after the dismissal criteria were met in both groups of schools. Estimate that the number of cases on the second day following reopening was 49% lower than would be expected if the school had not closed (adjusted for day of week, baseline case numbers, and time since beginning of school and city outbreaks). School closure estimated to reduce cumulative number of cases by ~7%.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Copeland et al (2012) [16]	Ecological study: household survey of families with children enrolled in schools in one district in which schools were closed in response to pandemic influenza and one district in which schools remained open.	5188 individuals in 1187 (of 2725 contacted) households in the school closure district; 4842 individuals in 155 (of 1944 contacted) households in the control district. Also general population of the two districts in analysis of emergency department data.	Response to outbreak.	Approx one week; all schools in the closure district.	Early in outbreak: each district had reported <70 laboratory-confirmed cases and ≤2 H1N1 hospitalisations.	Self-reported ARI; percentage of emergency department visits which were due to influenza. Estimated “difference in differences” comparing the rate difference for consecutive periods (e.g. before and during school closure) in the closure and non-closure districts. Also assessed the percentage difference between the observed ARI rate in the closure community and that expected if rates had increased in the same way as was seen in the control community.	In closure district, ARI rate was 0.6% before closure and 1.2% (twice as high) during, in the control district the rates were 0.4% and 1.5% (3.75 times as high). This corresponds to a difference in differences of -0.47 percentage points (p = 0.046). Effect was strongest in individuals aged ≥19 years. No evidence of any difference comparing closure period to period following reopening. ARI rate during closure estimated to be 29% lower than it would have been had schools not closed. ED visits for influenza increased 1.6 times in the closure district comparing periods before and during closure, and 2.1 times in the control district.

Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Monto et al (1970) [59]	Non-randomised community trial of pandemic vaccine	All schoolchildren in Tecumseh (approx 3680) and Adrian (number not stated), Michigan, November 1968 – January 1969. 86% of children and a small number of adults in Tecumseh were vaccinated against the pandemic strain. Pandemic vaccine was not used in Adrian.	Christmas holiday	Two weeks, presumably all schools	Peak absenteeism in Adrian occurred one week before closure; Tecumseh did not experience an extensive epidemic.	School absenteeism (all causes)	Absenteeism in Adrian was >14% on each of the four days before closure and was ~8% on the day of reopening. Tecumseh did not experience any clear peaks in absenteeism.
Bootsma and Ferguson (2007) [70]	Statistical / transmission modelling analysis of historical P&I mortality data	23 US cities with data on timing of introduction of NPIs during 1918 influenza pandemic	Response to outbreaks; other social distancing measures also implemented	Approx 0-7 weeks, depending on city	Varied by city	Excess total or peak mortality in each city	Correlation between excess / peak mortality and timing of introduction of NPIs relative to progress of epidemic ($p<0.01$ in both cases). Lifting of NPIs allowed transmission to become established again

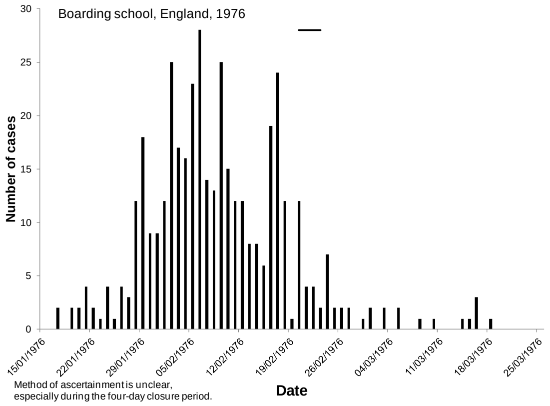
Study	**Study design**	**Study population / Setting**	**Nature of closure**	**Duration of closure and schools affected**	**Timing of closure in relation to influenza circulation**	**Outcome measure**	**Association between school closure and outcome**
Hatchett et al (2007) [75]	Statistical analysis of historical P&I mortality data	17 US cities, September – December 1918	Response to outbreaks; other social distancing measures also implemented	Varied by city	Varied by city	Cumulative Excess P&I death rates (CEPID)	Cities which closed schools before CEPID reached 30/100,000 had a lower median peak weekly excess P&I death rate than those which did not ($p<0.01$) but there was no significant difference in median CEPID. Closing schools at a higher CEPID was associated with higher peak P&I death rates (Spearman ρ =0.54) but not with total P&I death rates. Second waves occurred only after lifting of NPIs.

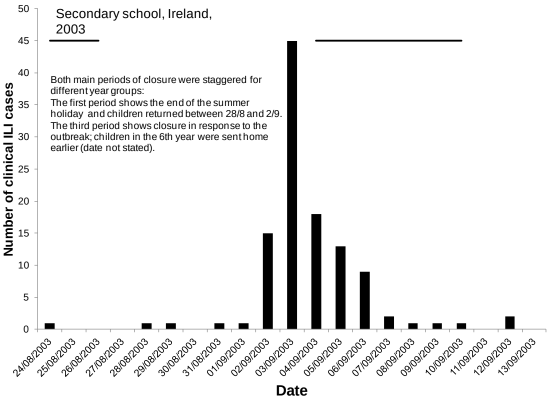
Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Markel et al (2007) [84]	Ecological analysis of historical mortality data	43 US cities, September 1918 – February 1919	Response to outbreaks; other social distancing measures also implemented	Varied by city	Varied by city	Weekly excess P&I death rates	Not uniform across cities (but this could be related to the timing of the intervention). Earlier interventions correlated with increased time to epidemic peak (r = -0.74, p<0.001), reduced peak excess death rate (r = 0.31, p=0.02) and reduced total excess death rate (r = 0.37, p=0.008). Increased duration of intervention associated with reduced total excess death rate (r = -0.39, p=0.005).
Jordan et al (1919) [165]	Outbreak report	Elementary school (391 pupils aged 4-13 years) and high school (427 pupils aged 14-18 years) of University of Chicago, October – December 1918	Planned Thanksgiving break	Four days (including weekend)	Both schools were closed for final three days of peak week and one day of the following week.	Clinical influenza (n = 97 in elementary school, n = 91 in high school)	Elementary school: incidence declined from 19 cases in peak week to 15 the following week, showed a second peak of 10 cases 3 weeks after the closure. High school: incidence decreased from 16 cases in peak week to 5 the following week, showed a second peak of 11 cases 2 weeks after the closure.

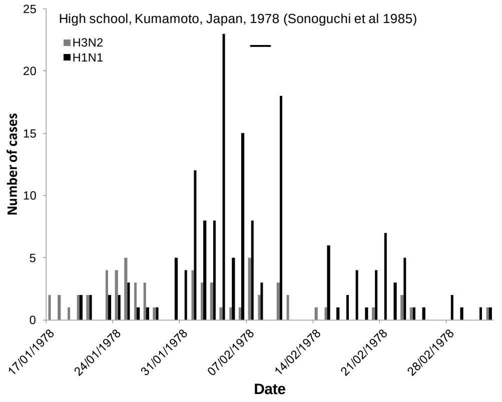
Study	Study design	Study population / Setting	Nature of closure	Duration of closure and schools affected	Timing of closure in relation to influenza circulation	Outcome measure	Association between school closure and outcome
Armstrong and Hopkins (1921) [62]	Outbreak report	Kelleys Island, Lake Erie, US, January – February 1920, population 689 (of whom 157 were schoolchildren)	Response to staff and student absenteeism during influenza outbreak	The single school (for both grammar and high school pupils) on the island remained closed "until the epidemic had subsided"	Epidemic began 24 January, school closed 30 January	Self-reported clinical influenza, based on checklist of symptoms (n = 369)	Overall incidence peaked at 52 cases on day following closure. Cases in schoolchildren dipped on day of closure, peaked following day and declined thereafter. Cases in other groups dipped two days after closure, peaked the following day and then declined.
Winslow and Rogers (1920) [42]	Outbreak report	Connecticut, USA, September – December 1918	Response to outbreak	Three cities in which schools remained open are cited and mortality rates compared descriptively with two cities in which schools were closed. Duration of closures not stated.	Not stated.	Deaths from pneumonia and influenza	Death rates were lower in the three cities in which schools remained open than in at least two cities in which they were closed.

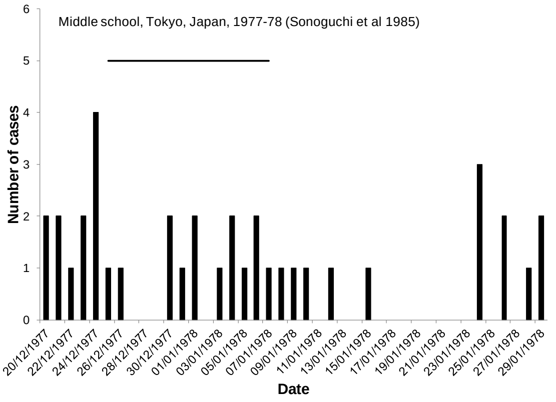
Appendix 7: Epidemic curves for seasonal influenza

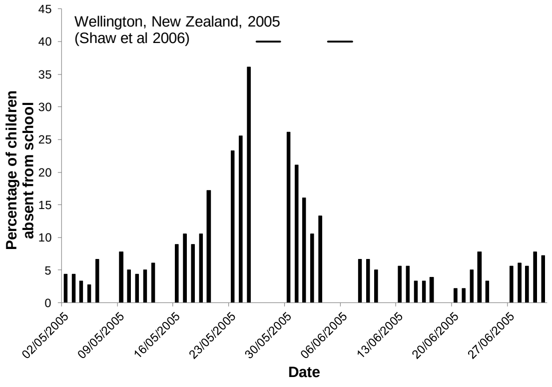
Horizontal lines show dates of school closures

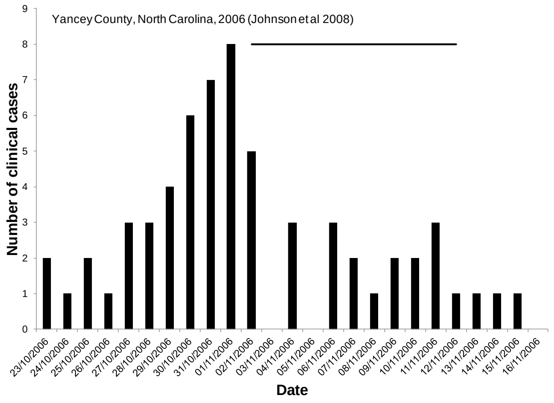


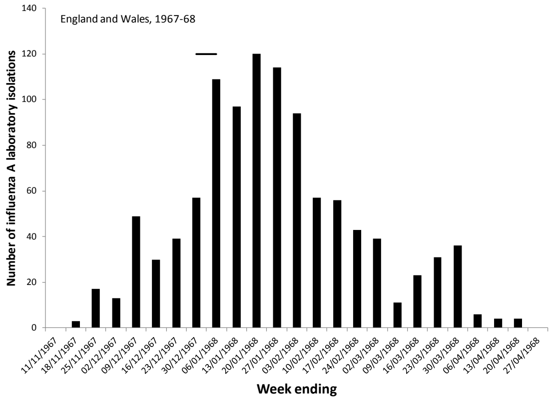


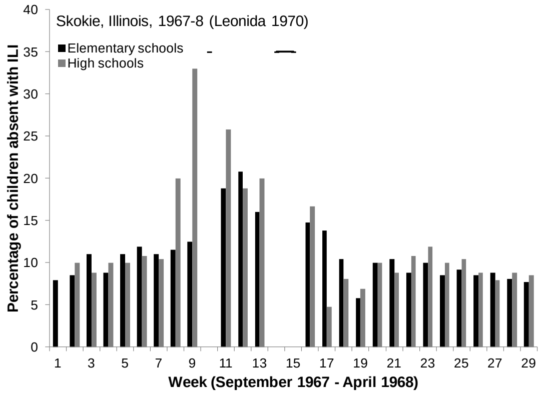


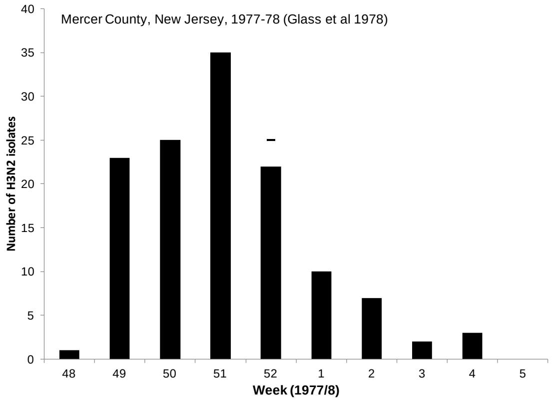


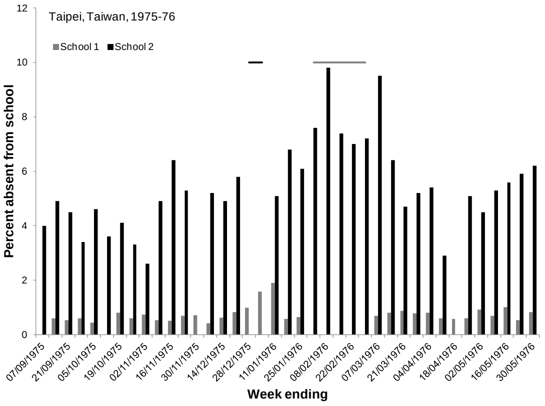


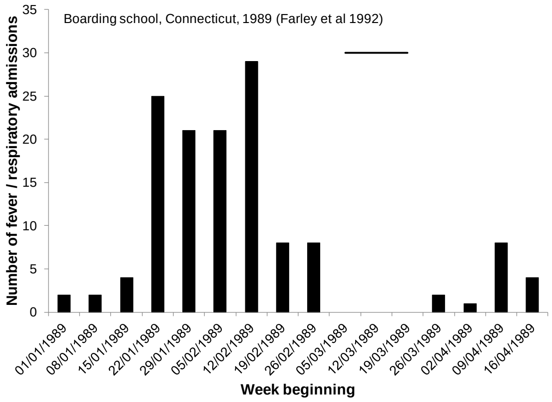


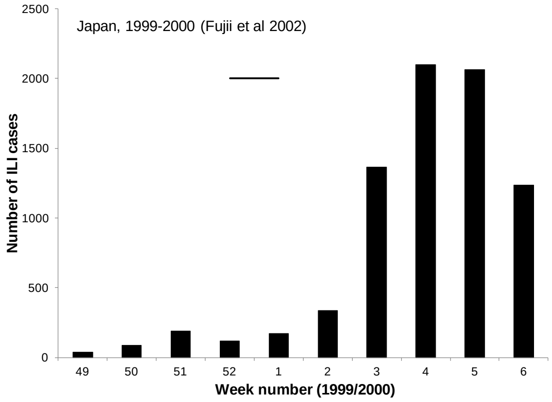


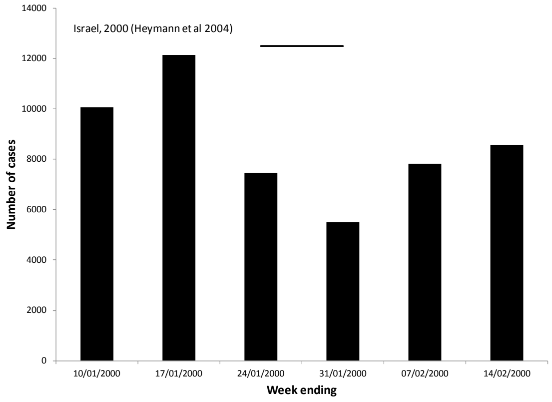


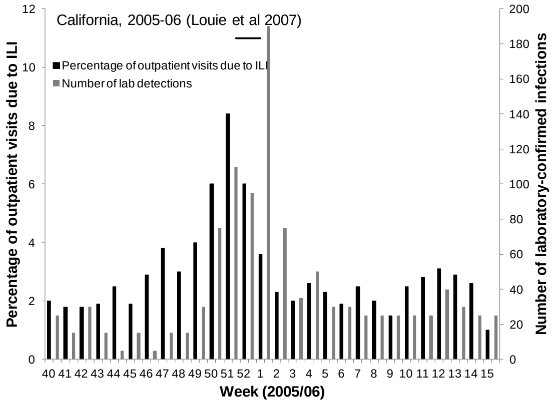

Mercer County, New Jersey, 1977-78 (Glass et al 1978)
Number of H3N2 isolates
0
5
10
15
20
25
30
35
40
48
49
50
51
52
1
2
3
4
5
Week (1977/8)

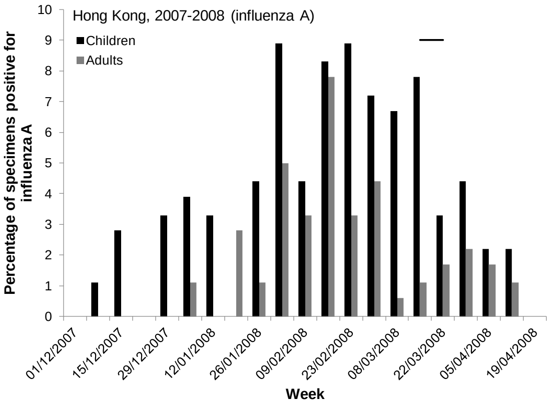

Taipei, Taiwan, 1975-76
School 1
School 2
Percent absent from school
0
2
4
6
8
10
12
07/09/1975
21/09/1975
05/10/1975
19/10/1975
02/11/1975
16/11/1975
30/11/1975
14/12/1975
28/12/1975
11/01/1976
25/01/1976
08/02/1976
22/02/1976
07/03/1976
21/03/1976
04/04/1976
18/04/1976
02/05/1976
16/05/1976
30/05/1976
Week ending

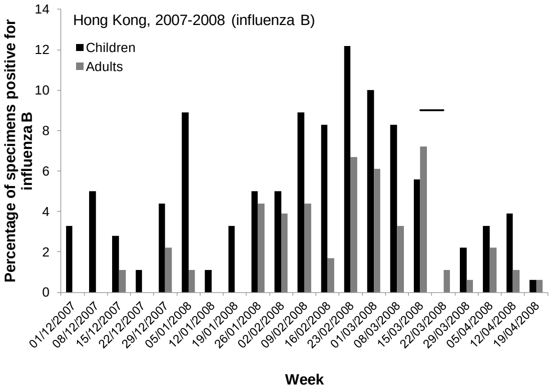

Boarding school, Connecticut, 1989 (Farley et al 1992)
Number of fever / respiratory admissions
0
5
10
15
20
25
30
35
01/01/1989
08/01/1989
15/01/1989
22/01/1989
29/01/1989
05/02/1989
12/02/1989
19/02/1989
26/02/1989
05/03/1989
12/03/1989
19/03/1989
26/03/1989
02/04/1989
09/04/1989
16/04/1989
Week beginning

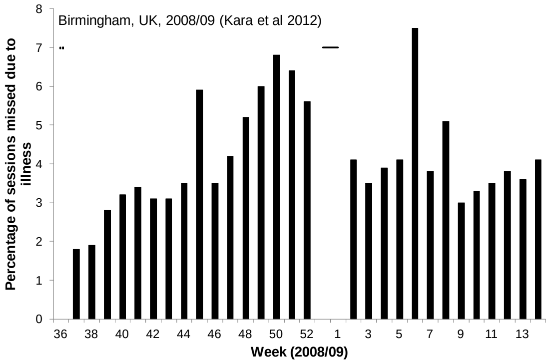

Japan, 1999-2000 (Fujii et al 2002)
Number of ILI cases
0
500
1000
1500
2000
2500
49
50
51
52
1
2
3
4
5
6
Week number (1999/2000)


Israel, 2000 (Heymann et al 2004)
Number of cases
0
2000
4000
6000
8000
10000
12000
14000
10/01/2000
17/01/2000
24/01/2000
31/01/2000
07/02/2000
14/02/2000
Week ending


California, 2005-06 (Louie et al 2007)
Percentage of outpatient visits due to ILI
Number of lab detections
Percentage of outpatient visits due to ILI
Number of laboratory-confirmed infections
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
180
200
40 41 42 43 44 45 46 47 48 49 50 51 52 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Week (2005/06)

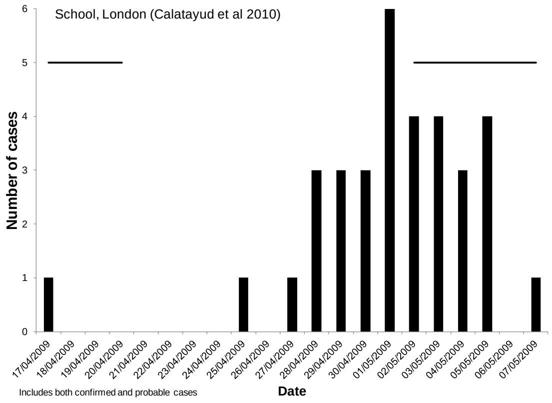

Hong Kong, 2007-2008 (influenza A)
Children
Adults
Percentage of specimens positive for influenza A
0
1
2
3
4
5
6
7
8
9
10
01/12/2007
15/12/2007
29/12/2007
12/01/2008
26/01/2008
09/02/2008
23/02/2008
08/03/2008
22/03/2008
05/04/2008
19/04/2008
Week


Hong Kong, 2007-2008 (influenza B)
Children
Adults
Percentage of specimens positive for influenza B
0
2
4
6
8
10
12
14
01/12/2007
08/12/2007
15/12/2007
22/12/2007
29/12/2007
05/01/2008
12/01/2008
19/01/2008
26/01/2008
02/02/2008
09/02/2008
16/02/2008
23/02/2008
01/03/2008
08/03/2008
15/03/2008
22/03/2008
29/03/2008
05/04/2008
12/04/2008
19/04/2008
Week


Birmingham, UK, 2008/09 (Kara et al 2012)
Percentage of sessions missed due to illness
0
1
2
3
4
5
6
7
8
36
38
40
42
44
46
48
50
52
1
3
5
7
9
11
13
Week (2008/09)

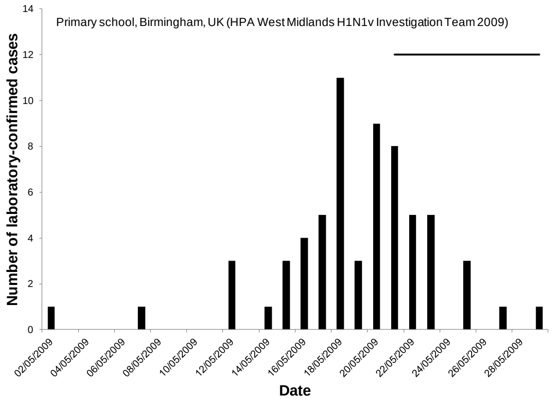
Appendix 8: Epidemic curves for pandemic influenza

Horizontal lines show dates of school closures

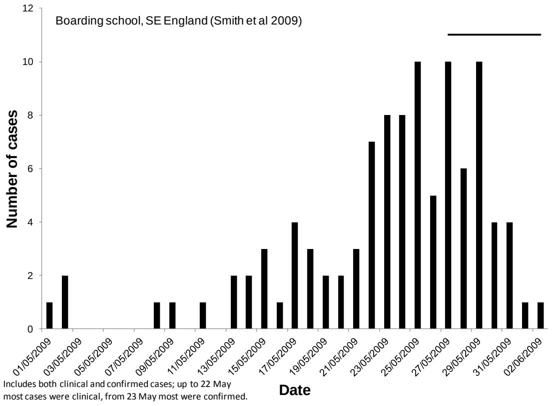


School, London (Calatayud et al 2010)

Includes both confirmed and probable cases

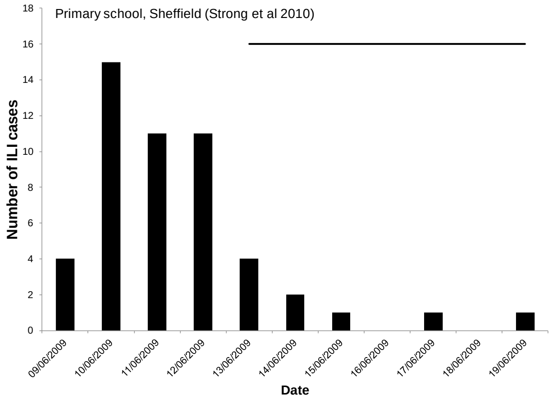


Primary school, Birmingham, UK (HPA West Midlands H1N1v Investigation Team 2009)

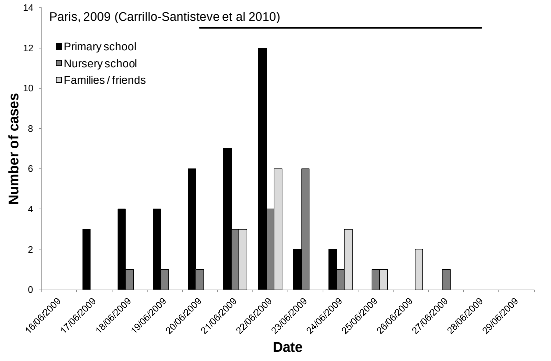


Boarding school, SE England (Smith et al 2009)

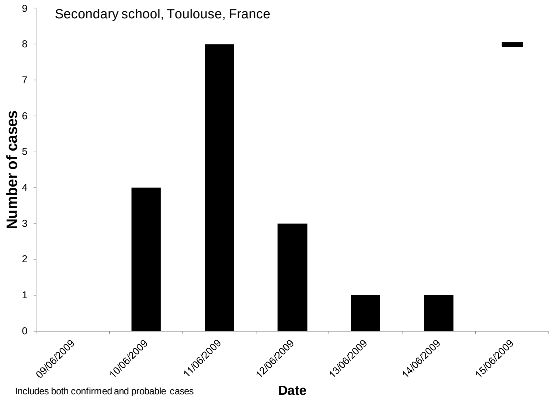
Includes both clinical and confirmed cases; up to 22 May most cases were clinical, from 23 May most were confirmed.



Primary school, Sheffield (Strong et al 2010)

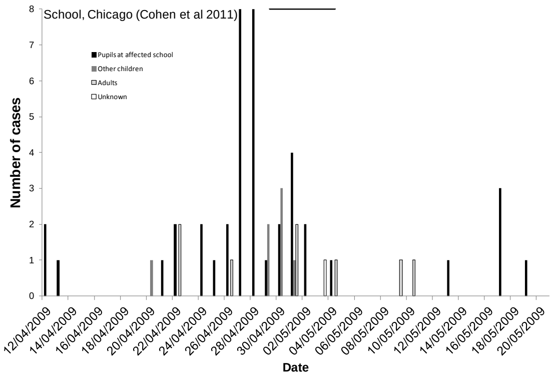


Paris, 2009 (Carrillo-Santisteve et al 2010)

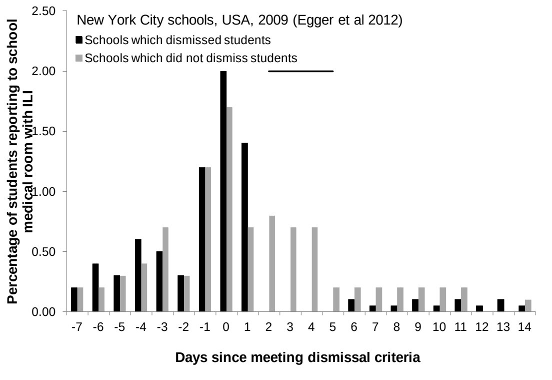


Secondary school, Toulouse, France

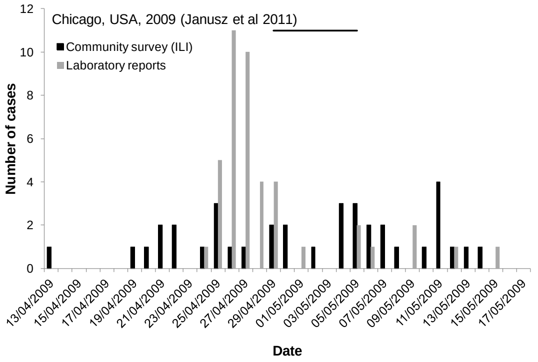
Includes both confirmed and probable cases

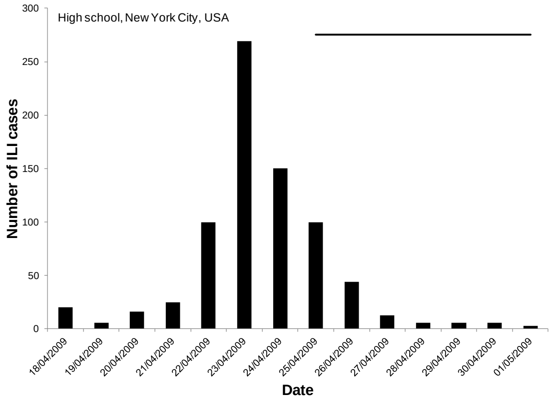


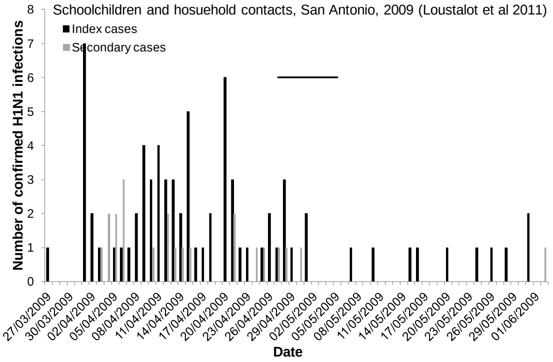
School, Chicago (Cohen et al 2011)

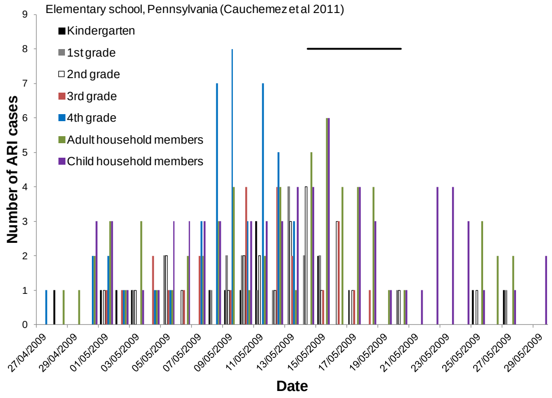


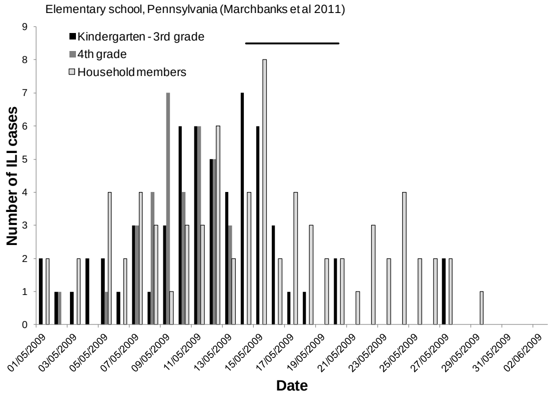
New York City schools, USA, 2009 (Egger et al 2012)

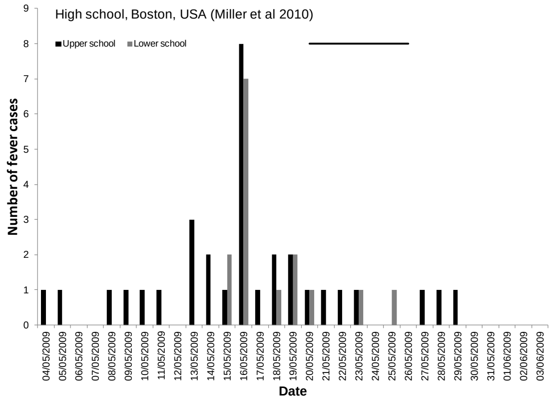

Chicago, USA, 2009 (Janusz et al 2011)

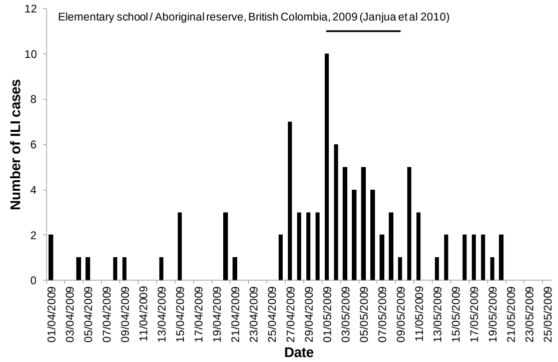

High school, New York City, USA

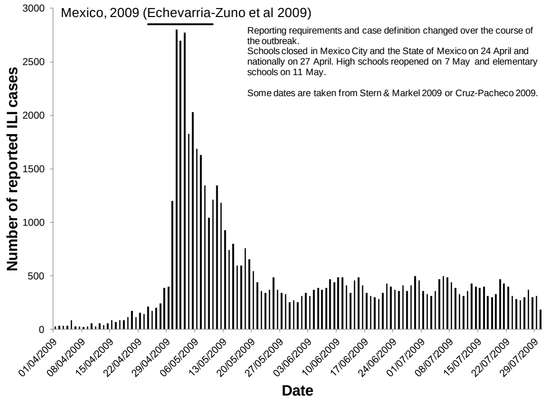

Schoolchildren and hosuehold contacts, San Antonio, 2009 (Loustalot et al 2011)


Elementary school, Pennsylvania (Cauchemez et al 2011)


Elementary school, Pennsylvania (Marchbanks et al 2011)

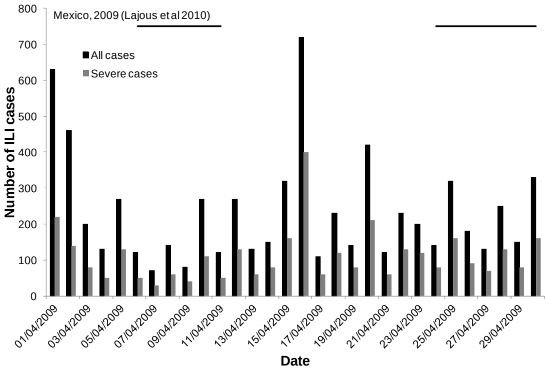

High school, Boston, USA (Miller et al 2010)

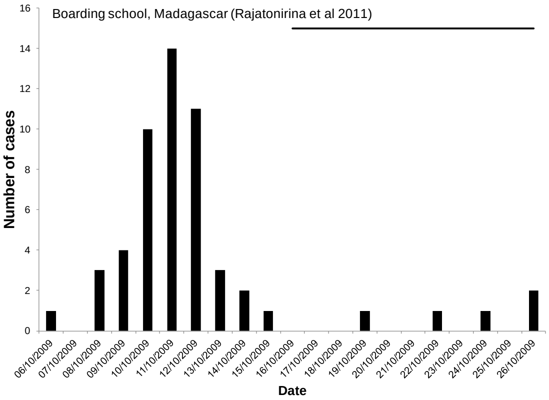

Elementary school / Aboriginal reserve, British Colombia, 2009 (Janjua et al 2010)

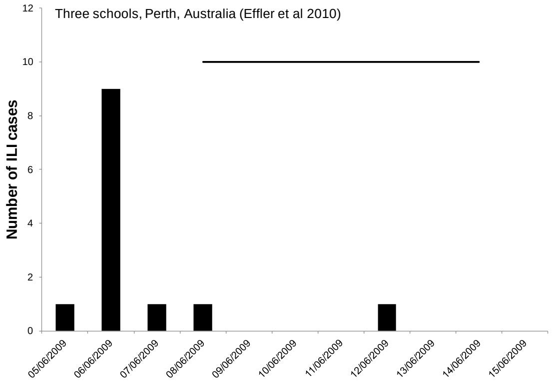

Mexico, 2009 (Echevarria-Zuno et al 2009)

Reporting requirements and case definition changed over the course of the outbreak.
Schools closed in Mexico City and the State of Mexico on 24 April and nationally on 27 April. High schools reopened on 7 May and elementary schools on 11 May.

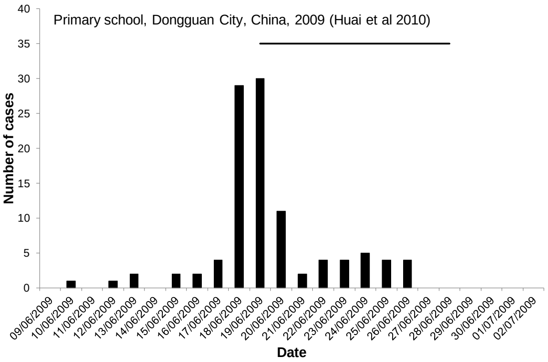
Some dates are taken from Stern & Markel 2009 or Cruz-Pacheco 2009.

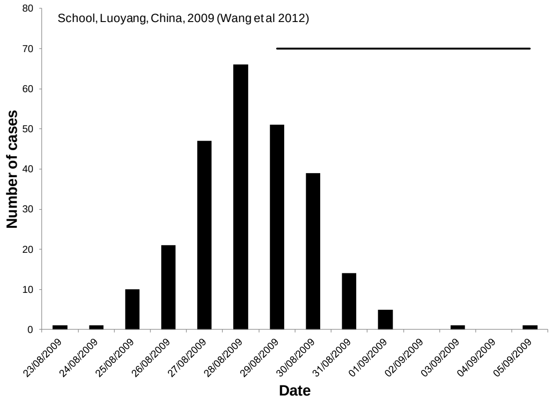


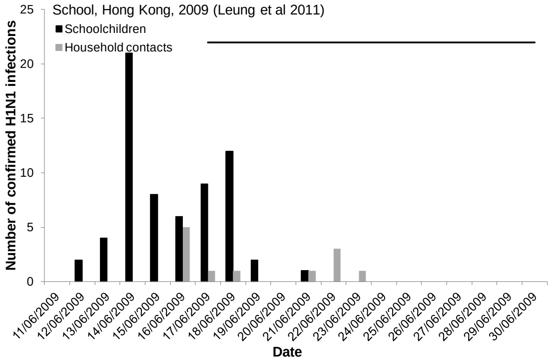


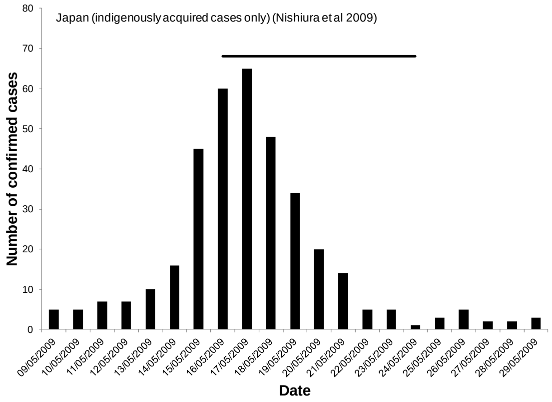


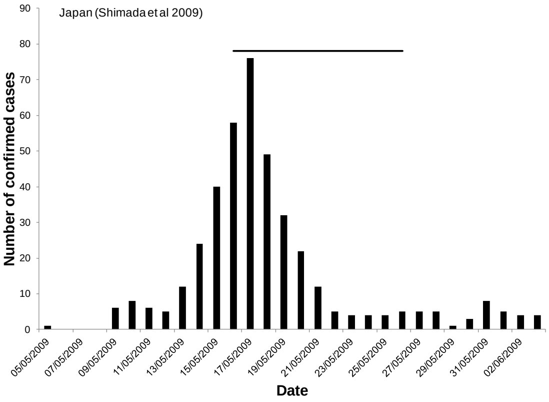
One school closed completely, one cancelled classes for one grade, and one cancelled classes for three grades

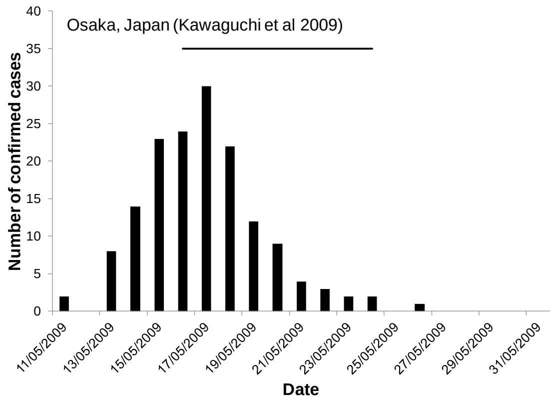


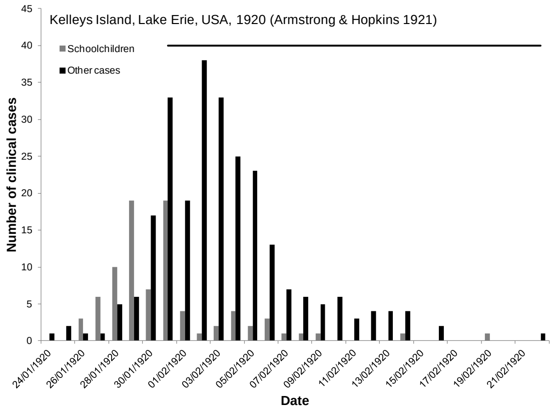


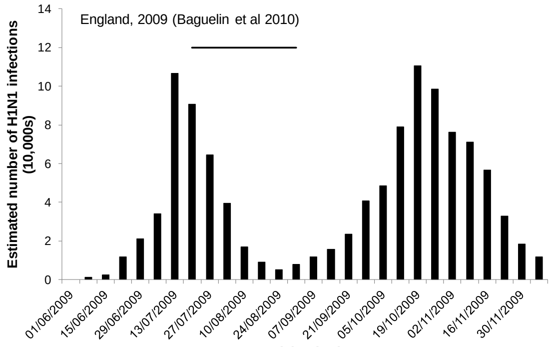




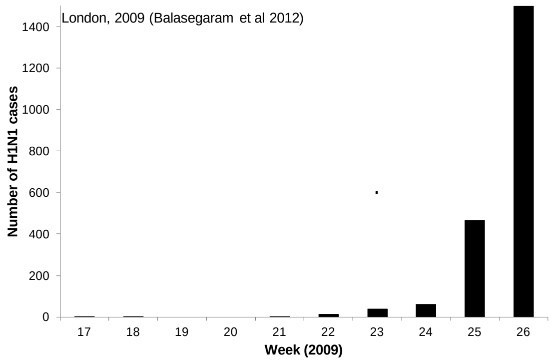


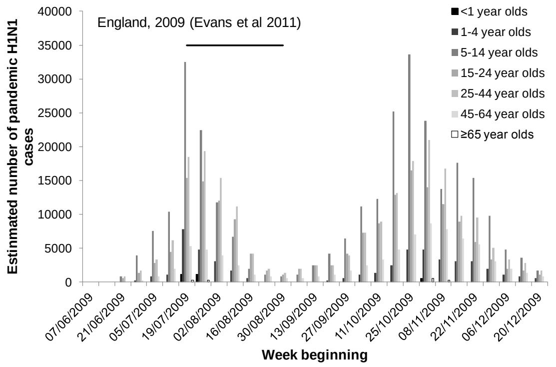


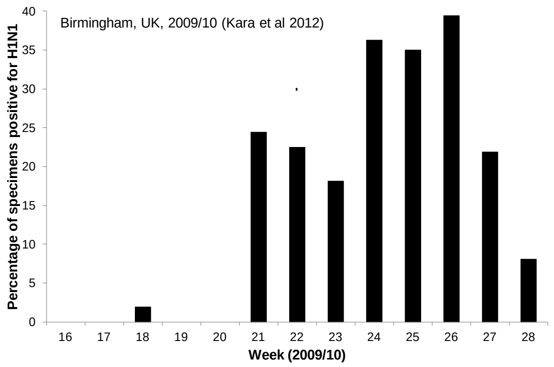


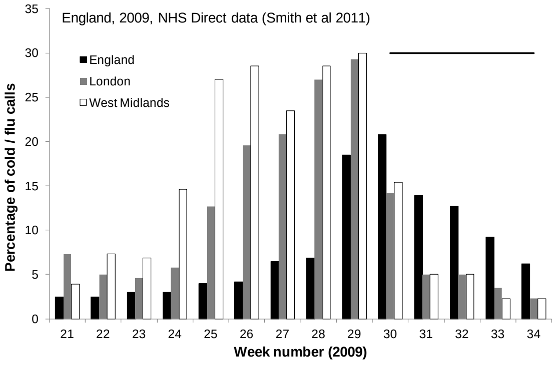


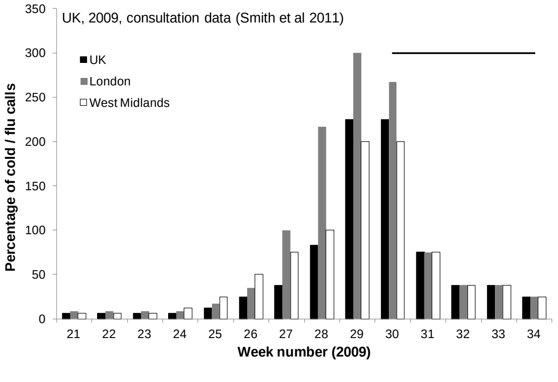
Precise closure dates varied across the country

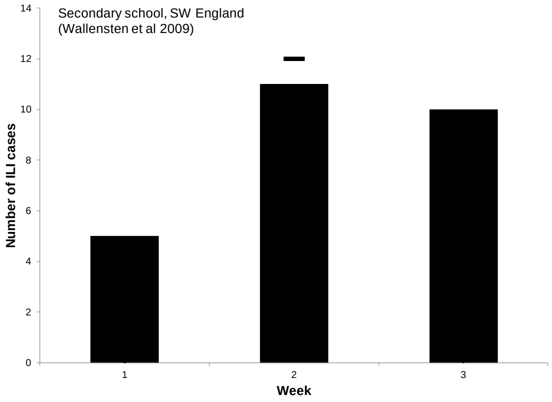


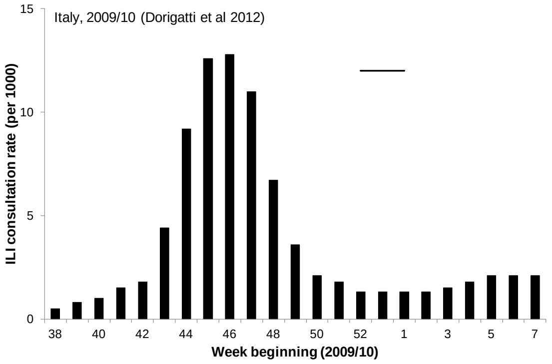


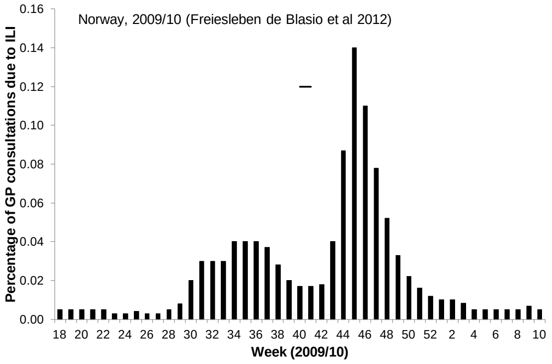


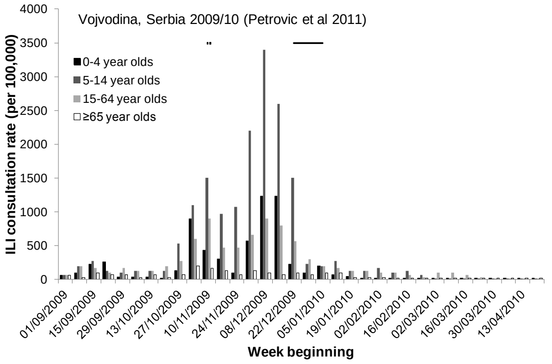


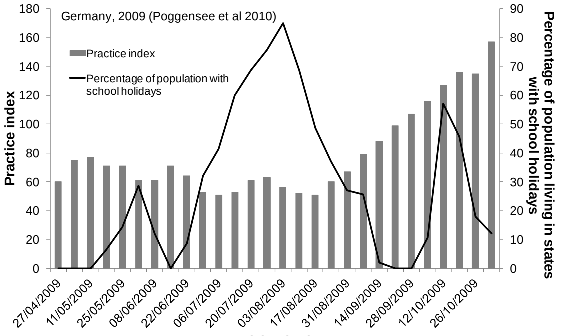




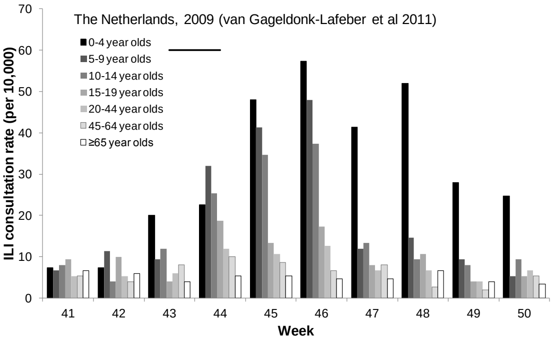




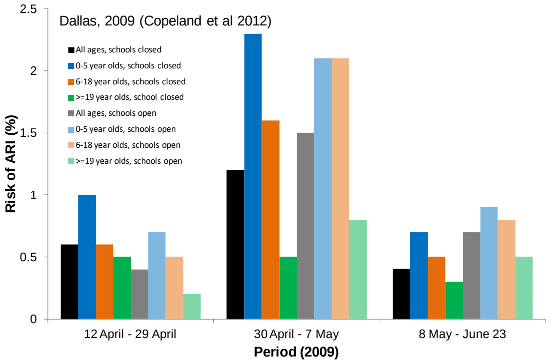


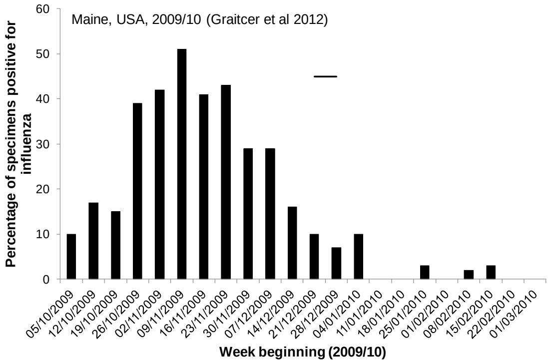


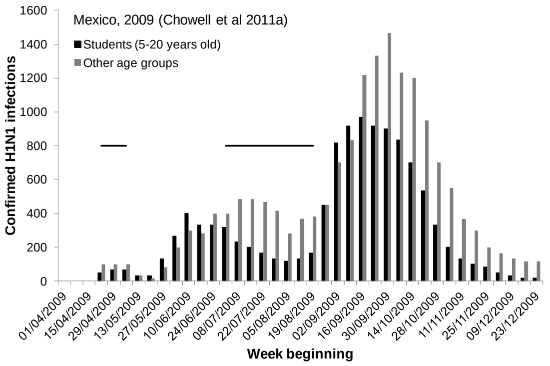
See Supplementary Information for definition of practice index

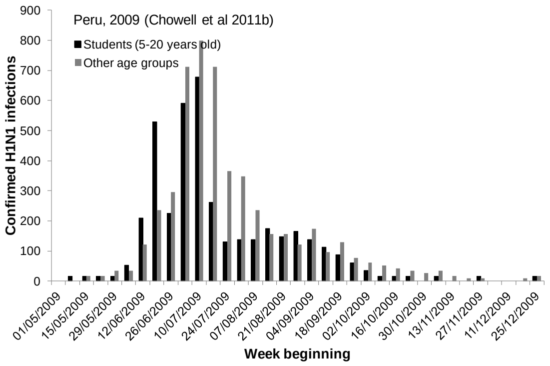


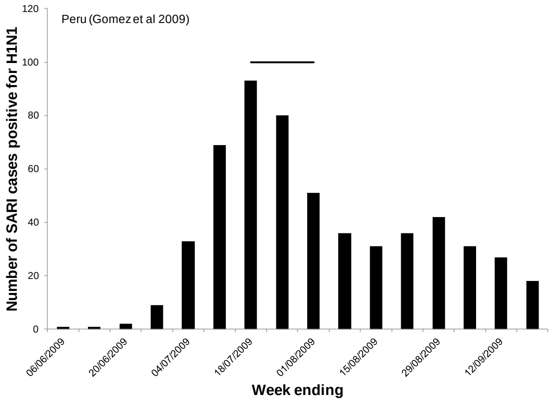
Schools were closed during week 43 (northern and central regions) or week 44 (southern regions)

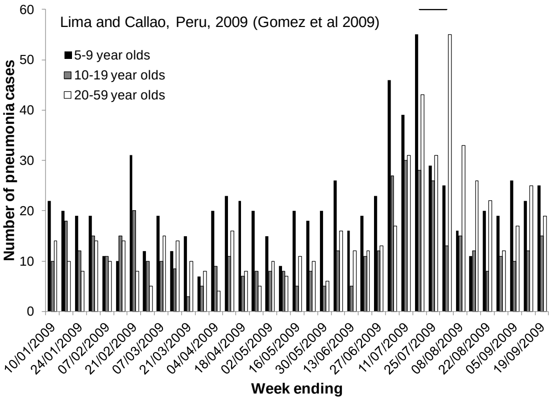


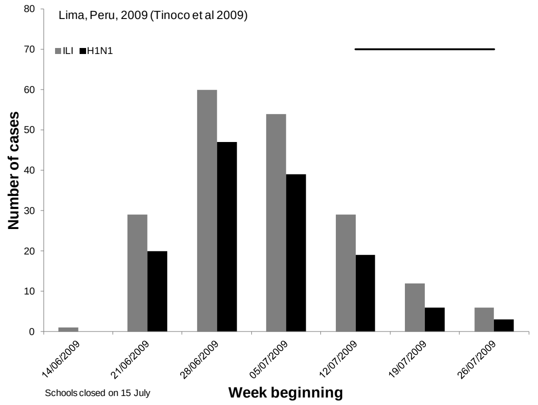




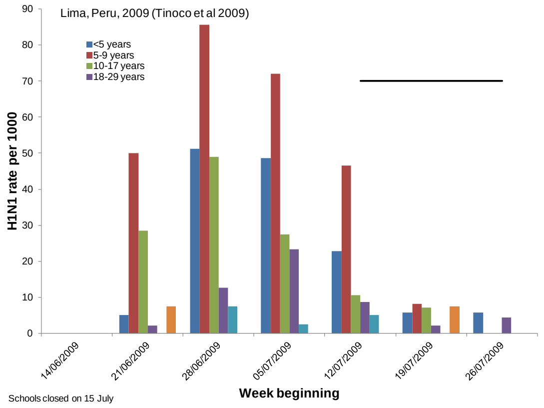




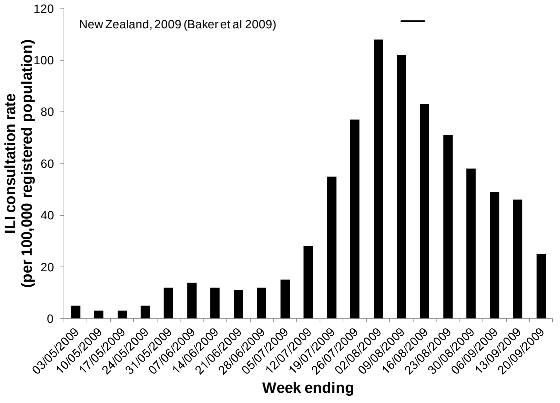


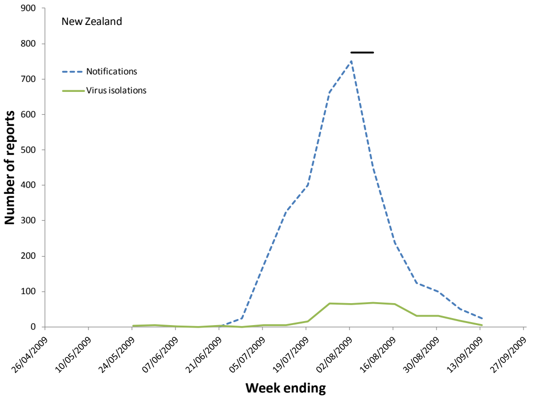


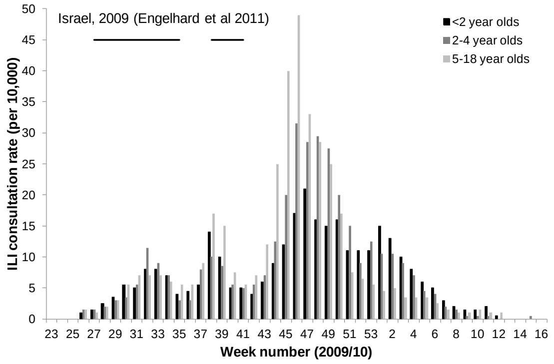
Schools closed on 15 July

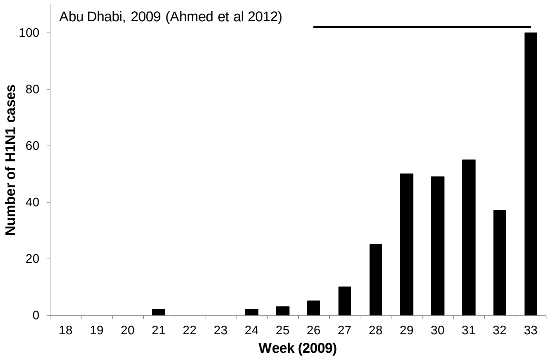


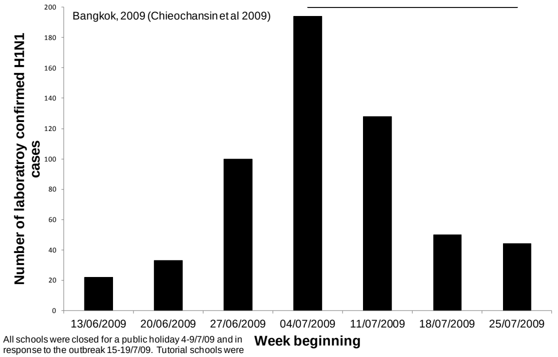
Schools closed on 15 July



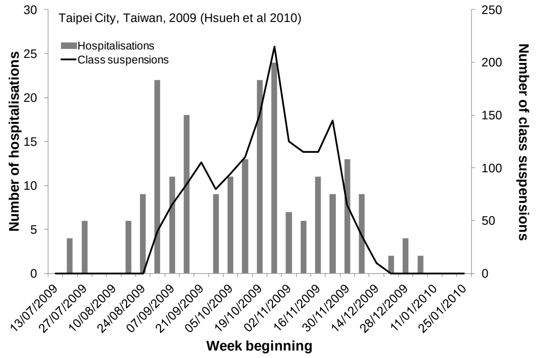


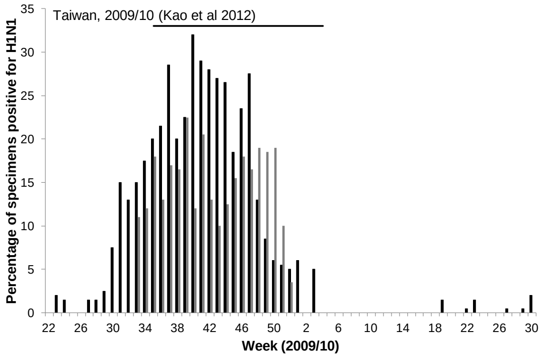




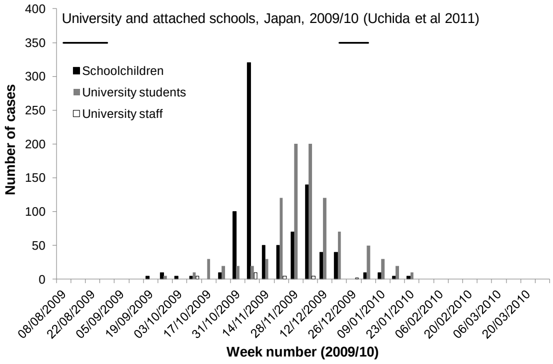


All schools were closed for a public holiday 4-9/7/09 and in response to the outbreak 15-19/7/09. Tutorial schools were closed 13-28/7/09





Varying numbers of individual schools were closed over the period indicated



Appendix 9: Mathematical modelling studies of the effects of school closure on pandemic influenza

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Individual based models							
Elveback et al (1976) [119]							
Hypothetical population structured to resemble a suburban US community. Age / location-specific contact rates chosen to produce age-specific ARs similar to those for the 1957 and 1968 pandemics. Contact rate greatest in playgroups, then family, then schools (1957) or neighbourhood clusters (1968), then neighbourhood clusters (1957) or schools (1968), then community.	Average latent period = 1.9 days Average infectious period = 4.1 days Baseline clinical ARs: 1957 – 35.4% (preschool) 61.8% (school), 23.4% (young adult), 13.1% (older adult), 35.1% (overall) 1968 – 35.2% (preschool) 35.7% (school), 32.1% (young adult), 30.4% (older adult), 33.3% (overall)	Schools either never opened following routine closure, or closed for the second week of the outbreak	Elimination of transmission in schools; no effect on other contact rates. No empirical basis stated for these assumptions.	NA	Reduced by 90% (using contact rates based on Asian influenza) or 27% (using contact rates based on Hong Kong influenza) if schools never opened, or by 20% with one week closure (Asian influenza)	NA	Not quantified, but stated that the effect of several days' closure during an outbreak of Asian influenza is greater than that on the cumulative AR.

Ferguson et al (2005) [139]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on Thai census (2000) and related data. Probability of contact sufficient for transmission maximum in schools, half this value in households and workplaces, and ~1/6 of this value in community. Schools and workplaces closed at the same time as antiviral prophylaxis is provided. Focuses on eliminating a pandemic at source.	R_0=1.1 – 2.0 Serial interval = 2.6 days, based on household study of seasonal influenza in 2000. Baseline clinical AR 17% if R_0 = 1.5, 25% if R_0 = 1.8..	Closure of 90% of schools and 50% of workplaces within 5km of a detected case , for 3 weeks.	Complete elimination of mixing in schools and workplaces. 100% increase in contact in households, and 50% increase in random contacts for individuals withdrawn from school / work. No empirical basis stated for these assumptions, but chosen to be conservative.	NA	>90% chance of eliminating epidemic (i.e. “preventing a large outbreak (which would eventually lead to a global pandemic)”) if $R_0 \leq 1.7$	NA	NA
Yasuda et al (2005) [109]							
Basis of population structure unclear. Contact rates based on time use data from 30000 individuals in Japan, collected at an unspecified time.	Latent period = 3 days “Period of infection” = 7 days Baseline AR not provided	Four days after start of outbreak; closure either maintained for duration of outbreak or reopened after 13 days.	Unclear; presumably complete elimination of contacts at school with no effect on other contacts. No empirical basis stated for these assumptions.	Reduced by ~45% (permanent closure) or ~12% (13 day closure)	Reduced by 12% (10% in adults, 17% in children, permanent closure) or essentially unchanged (13 day closure)	Increased by ~25% from 20 to 25 days (permanent closure) or ~35% from 20 to 27 days (13 day closure)	Increased by ~40% from 50 to 70 days (permanent closure) or ~20% from 50 to 60 days (13 day closure)
Ferguson et al (2006) [105]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Model as in [139] applied to population based on Great Britain / United States census data. Model incorporates simultaneous closure of schools and workplaces.	R_0 = 1.7 or 2.0 Serial interval = 2.6 days, based on same data as [139]. Sensitivity analysis used latent period = 1.2 days and infectious period = 4.1 days, and found that this reduced the impact of interventions. Baseline clinical ARs 28% (R_0 = 1.7) or 34% (R_0 = 2.0)	Each school and 10% (or 50%) of workplaces close from the day after detection of the first case in pupils or staff until up to 3 weeks after the last case in that school. Schools / workplaces can close repeatedly during the pandemic. Sensitivity analyses explored varying the threshold and duration of closure, and an alternative strategy of "area closure" in which all schools within 10km of a case close.	Elimination of transmission in schools and workplaces. 50% increase in contact rates in affected households; 25% increase in community contacts of affected individuals. No empirical basis stated for these assumptions. Sensitivity analysis increased household contacts by 70% but the predicted effects of school closures were "relatively insensitive" to this change.	Decreased by 25-33%, depending on R_0 and, much less importantly, on the proportion of workplaces closing. Duration of closure has little effect. Number of cases which triggers closure of each school has relatively little effect as long as it is <5. Similar results were obtained when area closure was introduced.	If R_0=2.0, decreased by 6-9% (from 34% to 32% or 31%, depending on proportion of workplaces closing). If R_0=1.7, decreased by 11-15% (from 27% to 23-24%). Longer closures were associated with slightly increased reductions. Number of cases in each school which triggers closure of that school has relatively little effect as long as it is <5. Similar results with area closure.	Delayed by 9-16 days, depending on R_0 and the proportion of workplaces closing.	NA

Germann et al (2006) [120]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on US census data (2000). Contact probability in household > preschool > schools and household clusters > neighbourhood and community. Model incorporates simultaneous closure of schools, preschools and playgroups.	R_0= 1.6 – 2.4 Mean latent period = 1.2 days Mean incubation period = 1.9 days Mean infectious period = 4.1 days Serial interval = 3.5 days Baseline AR 33-54% depending on $R_{0.}$ Age-specific attack rate pattern chosen to be in between those of 1957 and 1968. For R_0 = 1.6, clinical AR 35% (0-4 years) 50% (5-18 years), 27% (19-29 years), 28% (30-64 years), 24% (>64 years), 33% (overall).	All schools in the country closed seven days after pandemic alert, which occurs when 10,000 symptomatic cases have occurred nationwide (corresponding to a cumulative incidence of 3.6 / 100,000).	Elimination of mixing in school-related groups. No effect on other contact rates. Schools remain closed for the duration of the pandemic. No empirical basis stated for these assumptions.	NA	Predicted reduction ranged from 14% (if R_0 = 2.4) to 97% (if R_0 = 1.6)	Not quantified, but stated that social distancing policies slow pandemic spread	NA

Haber et al (2007) [106]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on US census data (2000). Number and duration of contacts vary with age and location. Household contacts last longer than community contacts and are fairly uniform with age whilst community contacts are fairly assortative. Transmission rates vary by age (0-4, 5-18, 19-64 and ≥65 years) according to an asymmetrical WAIFW matrix, but not by location (household, day-care centre, school, workplace, community, long term care facility). At weekends, duration of household and community contacts are doubled and no contacts occur elsewhere.	R_0 = 2.7 Latent period = 2 days Baseline clinical AR 32% overall (calibrated to age-specific ARs from 1957pandemic: 36% (0-4 year olds) 62% (5-18), 25% (19-64), 21% (≥65), 33% (overall))	Prevalence of infection of 10%, 15% or 20% in children at an individual school; schools remained closed for 7, 14 or 21 days.	Children from affected schools mix according to weekend contact patterns (i.e. contacts in schools eliminated; contacts in households and community doubled).	Decreased by ~30% if schools are closed for 14 days when prevalence reaches 10%.	Decreased by ~1-18%, depending on threshold and duration of closure: greater effect at lower thresholds; effect of duration of closure less clear. Less effective for lower values of R_0. Slightly greater effect if baseline contact intensity in schools increases.	Peak occurs 1 week earlier if schools are closed for 14 days when prevalence reaches 10%, compared to the no intervention scenario; no results presented for longer durations of closure.	Slight increase (~1 week) if schools are closed for 14 days when prevalence reaches 10%.
Cauchemez et al (2008) [7]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on French census data (1999); stratified by age into adults (≥18 years) and children (<18 years) with contact occurring in households, schools and community	R_0 = 1.8 during term time and 1.4 during holidays (estimated from data) Serial interval = 2.4 days Baseline clinical AR 31% (37-38% in children)	Daily incidence (all ages) ~20/100 000 or up to 1500/100000; schools closed permanently.	24 % reduction of child-to-child transmission, no effect on adults' contacts (based on analysis of French sentinel surveillance data covering term time and school holidays)	Decreased by 39-45% (47-52% in children). Reductions were smaller than this if schools closed at a higher threshold, e.g. 21% if threshold was 100 / 100,000 / day	Decreased by 13-17% (18-23% in children); greater reduction if schools closed at lower threshold. Reductions were smaller than this if schools closed at a higher threshold, e.g. 10% if threshold was 100 / 100,000 / day	NA	NA

Ciofi degli Atti et al (2008) [110]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on Italian census data (2001); structured into households, workplaces, day-care centres, schools, university and community. IBM coupled to SEIR model of global transmission.	R_0 = 1.4, 1.7 or 2.0 Baseline cumulative clinical AR 21.2%, 30.8% or 38.7%, depending on R_0. Latent period = 1.5 days Infectious period = 1.5 days (in SEIR model) Mean serial interval = 2.6 days (in individual-based model)	Four weeks after first 20 symptomatic cases in the individual-based model; schools remain closed for 4 weeks. All schools and some non-essential public offices closed.	Not stated.	No appreciable effect	No appreciable effect	Increased by 5-8 days (2.5-8.8%) depending on transmissibility (greater delay for higher R_0)	NA

Yasuda et al (2008) [111]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on Japanese census data (date not stated), related statistical data for Tokyo and its suburbs, and time use data. Probability of infection greatest in trains, then homes, then schools, then companies / stores.	Latent period = 2 days "Period of infection" = 5 days Baseline infection AR = 33%	1-4 weeks after start of epidemic; schools remained closed for 2 weeks.	Not stated.	Decreased by ~23% if schools closed after 1-3 weeks, or by ~38% if schools closed after 4 weeks.	Changed by <10% for all closure thresholds.	If schools were closed 1-2 weeks after the start of the epidemic, peak delayed by 2-3 weeks; otherwise the epidemic curve became bimodal, with the larger peak occurring 3 weeks after (if schools closed after 3 weeks) or 1 week before (if closed after 4 weeks) the peak for the unmitigated epidemic.	Increased by ~4 weeks for all closure thresholds.

Mniszewski et al (2008)[166]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on census data for southern California (2000). School closure modelled in combination with antiviral treatment / household prophylaxis from start of epidemic, and vaccination from 5 months (overlapping with the period of school closure by ~2 months)	Mean incubation period 1.9 days, “slightly longer than the latent period.” Mean infectious period 4.1 days Infection rate in children double that in adults Baseline clinical AR 30.6% $R_0 = 1.8$	Prevalence of symptomatic infection 0.1%; schools remain closed for six months	Children spend the time they would have spent at school at home instead; their other activities are not affected.	First wave peak AR decreased by ~98%; second wave peak AR 50-100% smaller than the unmitigated single peak, depending on vaccine properties.	Total AR (first and second waves) reduced by 28-96%, depending on vaccine properties	Reduced by ~1 week (for peak of first wave).	First wave duration increased by ~40 days; second wave may begin ~6 months after the end of the first and last for ~90 days

Milne et al (2008) [124]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on Australian census data (2001). 43% of infections occur in households, 29% in schools / workplaces, 26% in community. Model incorporates simultaneous closure of schools, childcare facilities and adult education institutions	R_0 = 1.5, 2.0 or 2.5 Latent period = 1 day Infectious period = 5 days (including 1 day asymptomatic), or 3 or 8 days in sensitivity analyses Baseline clinical attack rates 33%, 55% or 65%. Age-specific ARs calibrated against seasonal influenza data from Tecumseh, or 1968 pandemic.	Before the appearance of the first case; continued indefinitely.	School contacts eliminated; students and teachers spend the day at home so household contacts increase if others are present in the household. No effect on community contacts. If a child would otherwise be at home alone, an adult from the household stays at home and their workplace contacts are eliminated.	Reduced by 32-78%, depending on R_0 (greater reduction for lower R_0)	Decreased by 8-61%, depending on R_0 (greater reduction for lower R_0). Reduction of 59% if attack rates vary little with age, R_0 = 1.5 and 38%, 29% and 32% of transmissions occur in households, schools / workplaces and community, respectively.	NA	NA

Kelso et al (2009) [112]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [124], with emphasis on the timing of closing schools.	R_0 = 1.5, 2.5 or 3.5 Latent period = 1 day Infectious period = 5 days (including 1 day asymptomatic), or 3 or 8 days in sensitivity analyses Baseline clinical attack rates 33%, 65% or 73%. For R_0 = 1.5, baseline clinical ARs ~ 58% (0-5, 6-12 and 13-17 years), 44% (18-24 years), 40% (25-44 years) 25% (45-64years, ≥65 years), 33% (overall).	0-8 weeks after appearance of first infectious case; continued indefinitely.	As [124]	If R_0=1.5, decreased by ~80% if delay is up to 4 weeks; benefit decreases for longer delays, with essentially no reduction for a delay of 8 weeks. If R_0=2.5, decreased by ~33% for delays of 3 weeks or less, little effect if delay is 4 weeks or more.	If R_0=1.5, reduced by ~60% if delay is up to 3 weeks; benefit decreases for longer delays, with a reduction of ~22% for a delay of 8 weeks. For R_0 = 1.5 and pre-emptive closure, reductions in cumulative AR were ~57% (0-5 years), 64% (6-12 years) 66% (13-17 years), 57% (18-24 years), 58% (25-44 years), 56% (45-64 years), 52% (≥65 years). If R_0=2.5, reduction is <10% even if closures are implemented without delay.	If R_0=1.5, delayed by ~17 days for delays up to 4 weeks; longer delays bring the peak forward by up to ~16 days. If R_0=2.5, peak is delayed 5-12 days if closure is pre-emptive or within 2 weeks, otherwise little effect.	If R_0=1.5, increased by up to ~30 days; if R_0=2.5, increased by up to ~10 days.
Sander et al (2009) [141]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on US census data (2000). Structured into households, neighbourhood clusters, neighbourhoods, playgroups, day-care centres, elementary, middle and high schools, workplaces, and the community.	Baseline clinical AR = 50%	Implied that schools are closed immediately at the start of the pandemic; remain closed for 26 weeks (the duration of the pandemic)	Not clear	NA	Decreased by 22% (from 50% to 39%).	NA	NA
Timpka et al (2009) [140]							
Based on Swedish population (year not stated). Transmission probabilities highest in households, then schools, then community.	R_0 = 2.23 Incubation period 1.9 days, infectious period 4.1 days. Baseline AR not stated.	Not stated.	Contact at school eliminated, apparently no effects on other contact although this is not explicit. No empirical basis stated for these assumptions.	NA	NA	NA	NA
Sypsa & Hatzakis (2009) [138]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on Greek population (2001). Transmission probabilities greatest in households, then schools, then neighbourhoods, then community.	R_0 = 1.51 (estimated from model) Latent period = 1 day Infectious period = 4 days Transmission probabilities based on previous model[167] and modified to reflect data from 2009 H1N1 outbreak in La Gloria, Mexico. Baseline clinical AR 34.5% overall (59.7% in 0-18 year olds, 32.1% in 19-65, 23.8% in ≥65)	Cumulative clinical attack rate of 1%.	Unclear; presumably school contacts are eliminated (100% of schools shut). 60% of children comply and stay at home, it is not explicit how this affects their contact patterns compared to being at school or to not complying.	NA	Reduced by 89%	NA	Shortened by 11 days

Yasuda & Suzuki (2009) [113]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [111]; probability of infection in school altered to be consistent with values estimated for H1N1v outbreaks amongst children in non-school settings. School closures modelled in combination with self-isolation of all student cases and 1/3 of adult cases.	Latent period = 2 days; “Period of infection” = 5 days. Baseline infection AR = 36%	One or two weeks after start of outbreak, lasting for 4-7 days.	Not clear	Effects ranged from a decrease of 26% to an increase of 3%, depending on timing and duration of closure (compared to scenario with self-isolation alone): the greatest reduction was associated with the earlier closure (1 week after the start of the outbreak) but duration of closure had little effect if it was 5 days or greater.	Ranged from an increase of 0.7% to a decrease of 17%, depending on timing and duration of closure (compared to scenario with self-isolation alone): the greatest reductions were associated with the earlier closure (1 week after the start of the outbreak) and longest duration of closure.	Delayed by 1-2 weeks, depending on timing and duration of closure (compared to scenario with self-isolation alone).	Little or no apparent effect.

Lee et al (2010) [118]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on census data for Allegheny County, Pennsylvania, USA (2000). Transmission parameters based on previous models [105, 142, 168] and greatest in households, then workplaces, then schools, then community.	R_0 = 1.4, 1.7, 1.9 or 2.4 Baseline infection AR ranged from 35.1% (if R_0 = 1.4) to 53% (if R_0 = 2.4). Latent and infectious periods not stated.	Threshold prevalence of symptomatic cases in population of 0.1%, 0.5%, 1.0% or 1.5% if whole school systems are closed; or one day after the occurrence of 1, 5 or 10 symptomatic cases in the school if individual schools are closed. Duration of closure varied from 1 to 16 weeks.	Contacts at school eliminated, no effect on community contacts.	Ranged from a reduction of 63.2% (if R_0 was 1.4 and individual schools were closed for 16 weeks at a threshold of 1 case per school) to an increase of 9.2% (if R_0 was 2.4 and individual schools closed for 1 week at a threshold of 1 case per school). No consistent differences between reductions predicted with closure of individual schools compared to the whole school system.	Ranged from a reduction of 44.7% (if R_0 was 1.4 and individual schools were closed for 16 weeks at a threshold of 1 case per school) to an increase of 1.7% (if R_0 was 1.7 and the whole school system was closed for 1 week at a threshold prevalence of 1% of the population). No consistent differences between reductions predicted with closure of individual schools compared to the whole school system.	Could be delayed by up to 28 days if R_0 = 1.4 and whole school system is closed for 8 weeks at a threshold prevalence of 1% or less; other scenarios suggested shorter or no delays to the peak.	Difficult to assess precisely from graphs presented, but suggests an increase is likely (~10-20 days).
Chao et al (2010) [128]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on metropolitan Seattle.	R_0 = 2.0 Baseline clinical AR 33% Infectious period = 6 days, beginning one day after becoming infected. Incubation period 1-3 days.	Threshold not stated; schools closed either for 60 days or permanently.	Contacts at school eliminated, household contacts increased by an unspecified amount, community contacts doubled.	Peak prevalence reduced by ~67% if schools closed permanently; if schools reopened after 60 days, epidemic was bimodal, with the first and second peaks in prevalence ~33% and 50% the size of the peak in the unmitigated case, respectively.	NA	Peak prevalence delayed by ~24 days; the second peak occurs ~10 days later (when schools are closed for 60 days).	Increased by ~90 days.

Chao et al (2011) [136]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Model as in Chao et al (2010) [128], adapted for H1N1 pandemic in LA County (primary studies vaccination).	$R_0 = 1.3$ Baseline infection AR 23% Generation interval 3.4 days	For local, individual school closures, each school closed for 7 days following one case in the school. For county-wide school closure, all schools in the county close for 7 days at an unspecified threshold	Not stated.	Peak prevalence reduced by ~5% by county-wide closures or ~26% by local closures.	Both strategies “did not elicit any substantive decrease” (this is not quantified further).	County-wide closures delayed the peak by ~1 week; local closures by ~4-5 weeks.	County-wide closures had little effect on duration; local closures increased the duration of the epidemic but it is not clear by how much.

Halder et al (2010) [129]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [124] with emphasis on 2009 pandemic	$R_0 = 1.5$ Baseline clinical AR 32.5%. Mean infectious period = 5.5 days (including 1 day asymptomatic), Mean generation time ~2.5 days	1 case in a class triggers isolation of that case and their class ("school case isolation" strategy); 1 case in a primary school triggers closure of that school; 1 case in a secondary school triggers isolation of that class while 2 cases trigger full closure ("individual school closure" strategy); 30 symptomatic cases in the community (0.1% of the population) trigger closure of all schools ("all school closures" strategy). Closure lasted 1-4 weeks in all cases.	School contacts eliminated; students and teachers spend the day at home so household contacts increase if others are present in the household. No effect on community contacts. If a child aged 5-12 would otherwise be at home alone, an adult from the household stays at home.	Reduced by ~13% (school case isolation), ~23% (individual school closure) or ~7% (all school closure) if closed for 1 week; individual school closure resulted in greater reductions with longer periods of closure (e.g. ~63% with 4 week closure)	Reduced by ~8% (school case isolation or individual school closure) or ~2% (all school closure) if closed for 1 week; individual school closure resulted in greater reductions with longer periods of closure (e.g. ~23% with 4 week closure)	No apparent effect of school case isolation; individual or all school closure delayed peak by ~10 days	Possible slight increase of ~10 days for all strategies.

Kelso et al (2010) [169]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [124] with emphasis on antiviral treatment strategies and delays. Compares various antiviral treatment / prophylaxis strategies with and without school closures.	R_0 = 1.5 (or 1.2, 2.0 or 2.5 in sensitivity analyses) Baseline clinical AR 24.5% Serial interval 2.32 days	Two diagnosed cases in a school triggers closure of that school for two weeks.	School contacts eliminated; students and teachers spend the day at home so household contacts increase if others are present in the household. No effect on community contacts. If a child aged 5-12 would otherwise be at home alone, an adult from the household stays at home.	For each antiviral strategy, adding school closure reduced the peak incidence by up to 50% compared to using antivirals alone (assuming no delay in diagnosis; effects decreased as delay increased).	For each antiviral strategy, adding school closure reduced the cumulative AR by ~20-30% compared to using antivirals alone (assuming no delay in diagnosis; effects decreased as delay increased).	Delayed by ~40 days for each antiviral strategy.	Increased by up to 40 days, depending on antiviral strategy.

Halder et al (2010) [131]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [124] with emphasis on timing and duration of closure.	R_0 = 1.5, 2.0 or 2.5. Baseline clinical attack rates 33%, 50% and 59% for the respective values of R_0. Serial interval 2.49, 2.36 or 2.21 days.	Individual school closure strategy: 1 case in a primary school triggers closure of that school; 1-2 cases in a high school leads to isolation of students in the affected class; >2 cases in a high school triggers closure of the whole school. Closures occurred only when daily incidence in the community exceeded threshold levels between 0.003% and 0.333%. Simultaneous school closure strategy: all schools close when incidence in the community exceeds the thresholds above.	As [124].	Maximum reduction of 73% (R_0 = 1.5) or 38% (R_0 = 2.5), depending on timing and duration of closure. Optimal threshold depended non-linearly on duration of closure.	Maximum reduction of 42% (R_0 = 1.5), 18% (R_0 = 2.0), 8% (R_0 = 2.5) depending on timing and duration of closure. Optimal threshold depended non-linearly on duration of closure.	Maximum delay ~45 days (if R_0 = 1.5, schools closed for 8 weeks and closure was optimally timed). Smaller delays were possible with higher values of R_0.	Markedly increased, particularly for low values of R_0.
Barrett et al (2011) [122]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population of 150,000 based on US census data; activities based on time use data (year of collection not stated).	Baseline attack rate (including individual preventive measures) 26.3%.	School close when "1% of the total population is infected"; closure lasts for two weeks. School closure is modelled in conjunction with personal preventive behaviours (e.g. buying over the counter antiviral medication and avoiding unnecessary trips), which vary with age and socioeconomic group.	Contacts at school appear to be eliminated although other contacts between children are not: 75% of children stay at home throughout closure whilst 25% continue their usual after-school activities. If a child aged ≤13 years would otherwise be alone at home, an adult stays at home to care for them.	Peak prevalence in children reduced by ~78% compared to the scenario with preventive behaviours only. No clear effect for adults or elderly.	Reduced by 40% compared to the scenario with preventive behaviours only.	Epidemic becomes bimodal. For children, peaks with school closure occur ~14 days before and ~3 days after the peak in the scenario with preventive behaviours only. No clear effect in adults; peak brought forward by ~3 days in elderly.	Shortened by ~20 days in children, adults and elderly.
Andradóttir et al (2011) [123]							
Population based on Hamilton, Ontario, using Canadian census data from 2001 and 2006.	$R_0 = 1.4$ Mean latent period 1.9 days; mean infectious period 4.1 days. Baseline clinical attack rate 34.1%.	Each school closes for 5 days if ≥5 cases are identified in that school.	Not stated. School closure modelled in conjunction with a reduction of 20% in contacts in workplaces and the general community.	NA	Reduced by 30% overall. Effect largest in adults (40% reduction) and smallest in schoolchildren (22% reduction).	NA	NA

Yang et al (2011) [134]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Population based on Eemnes, The Netherlands (population 8382). Behaviour based on time use data, data on household size and land use data (further details not specified).	R_0 = 1.79 Latent period 1-3 days Infectious period 3-6 days Baseline attack rate 68%	Schools closed the day after prevalence reaches 20 infections in the population.	Contacts at school eliminated; effects on other contacts unclear.	Reduced by 28.9%	Reduced by 4.2%	Delayed by 8 days	Increased by ~2 weeks
Mao (2011) [135]							
Population based on US census data (2000) for Buffalo, New York. School closure modelled in combination with closure of 10% or 33% of workplaces.	R_0 = 1.3 – 1.4 Average latent period 2 days Infectious period 4-7 days Baseline clinical attack rate 18.6%	Schools closed when cumulative number of symptomatic infections exceeds 1000 (~1% of population).	Contacts at school presumably eliminated, effects on other contacts not stated.	Reduced by ~63% if 10% of workplaces close or ~85% if 33% of workplaces close.	Reduced by 36% if 10% of workplaces close, or 74% if 33% of workplaces close.	Delayed by 3 days if 10% of workplaces close; brought forward by 8 days if 33% of workplaces close.	Increased by ~30 days
Zhang et al (2011) [132]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on population of Singapore, including location-specific numbers of contacts collected in a survey in 2008 (details of the collection of these data and the definition of contact are not provided)	R_0 = 1.9 (or 1.5 or 2.3 in sensitivity analyses) Mean generation time 2.5 days Baseline clinical AR 44%	Schools closed when prevalence reached 0.02, 0.25, 1.5 or 5%, for a duration of 2, 4, 6, 8 or 10 weeks. Thresholds of 10 and 15% also investigated for closure lasting 2 weeks.	Contacts at school eliminated, no change in contacts occurring elsewhere.	Reduced by ~0-27% depending on threshold and duration of closure. Increasing duration of closure has little effect if it is 4 weeks or longer. Increasing threshold has little effect if it is ≤1.5% and duration is ≥4 weeks.	Reduced by <10% for all combinations of closure threshold and duration. Larger reductions as duration of closure increased up to 6 weeks, little additional benefit (and slight increase in cumulative AR if closure occurred late) to increasing duration beyond this unless the threshold was 0.02%.	Delayed by up to 5 days	NA
Morimoto & Ishikawa (2010) [137]							
Population based on Sapporo city, Hokkaido, Japan, using census and other data from 2000, 2005 and 2007.	R_0 = 2 Baseline infection attack rate 58%	All schools in a ward closed the day following diagnosis of an individual in that ward.	Not stated.	Reduced by 48%	Reduced by 14%	Delayed by 45 days.	Increased by ~70 days
Halder et al (2011) [130]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [124], with an emphasis on cost-effectiveness of interventions during a pandemic with characteristics similar to that of 2009.	R_n = 1.2, 1.5 or 1.8 Baseline clinical attack rate 13%, ~25% or ~33% for the respective values of R_n.	As [129]; schools are closed for 2, 4 or 8 weeks or permanently.	As [129]	NA	Reduced by 35-75% if R_n = 1.2, ~28-64% if R_n = 1.5, or ~18-42% if R_n = 1.8. Larger reductions with longer duration of closure.	NA	NA
Zhang et al (2012) [133]							
Population structure based on Singapore population data. School closure modelled in isolation or (primarily) in combination with partial closure of workplaces.	R_0 = 1.9 (1.5 or 2.3 in sensitivity analyses) Mean generation time 2.5 days Baseline clinical attack rate 44%	Schools close at a threshold incidence of either 0.02%, 0.25%, 1.5% or 5%, in the whole population. Schools remain closed for 2, 4, 6, 8 or 10 weeks.	Contacts at school eliminated; no effect on contacts elsewhere. Baseline contact patterns were based on a contact survey, but details are not given and the empirical data do not appear to include the effects of school closures.	Decreased by up to 28% by school closure alone.	Decreased by up to 9% by school closure alone.	Peak delayed by 5 days by school closure alone.	NA

Network models

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Carrat et al (2006) [107]							
Based on French census data (year not stated). Networks within households, schools, workplaces, nursing homes and districts.	Average baseline clinical AR 33% overall (54% in 0-18 year olds, 28% in 19-65 year olds, 25% in >65s). R_0 estimated as 2.07 and serial interval as 2.44 days. Latent period 0.5 days Infectious period up to 10 days, peak infectiousness 2-3 days post-infection.	5 infections / 1000 over an unspecified time period. Schools reopened 10 days after the last observed infection.	Not explicit	Decreased by ~90% if only schools closed, or by ~97% if schools and workplaces closed.	Decreased by 79% if only schools closed (87% in children, 75% in adults, 76% in elderly), or by 98% if schools and workplaces closed (97% in children, 98% in adults, 97% in elderly).	No appreciable effect if only schools closed; peak is ~25 days earlier if schools and workplaces are closed.	Increased by ~30% if only schools are closed, or reduced by ~60% if schools and workplaces are closed.
Glass et al (2006) [108]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Based on US census data (2000). Household networks with mean link contact frequency (MLCF) 6/day; extended family / neighbourhood network with mean of 12.5 members and MLCF 1/day; school class network(s) of 20-35 with MLCF 6/day (children) or 1/day (teenagers); workplace network of 10-50 with MLCF 1/day; networks for gatherings of 5-20 older adults with MLCF 1/day; random links (3 in same age class, MLCF 1/day, across all ages MLCF 0.04/day.	R_0=1.6 (estimated from model) Mean latent period = 1.25 days Infectious period = 2 days (including 0.5 days pre-symptomatic) Baseline clinical AR 25% overall (39% in children, 36% in teenagers, 22% in adults, 12% in older adults).	90% or 50% of schools closed the day following the 10th symptomatic case.	Elimination of contacts at school, doubling of household contacts with or without doubling of other non-school contacts. Also assessed keeping children and teenagers at home for the duration of the pandemic. No empirical basis stated for these assumptions.	Ranged from a reduction (from baseline of 7%) of 94% if children and teenagers were kept at home and compliance was 90%, to an increase of 27% if non-school contacts were doubled and compliance was 90%	Ranged from a reduction of 93% if children and teenagers were kept at home and compliance was 90%, to an increase of 18% if non-school contacts were doubled and compliance was 90%	Ranged from a reduction of 19 days if children and teenagers were kept at home and compliance was 90% to an increase of 15 days if children only were kept at home and compliance was 90%	Ranged from a reduction of 20 days if children and teenagers were kept at home and compliance was 90% to an increase of 59 days if children and teenagers were kept at home and compliance was 50%

Davey & Glass (2008) [121]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [108], with emphasis on rescinding control measures	R_0 = 1.6 or 2.0. Latent period = 1.5-2 days Infectious period = 1.5-2 days Baseline clinical AR 25% or 36%, depending on R_0	10 diagnosed cases within the community. Schools re-opened when 0, 1, 2 or 3 cases occur in 7 days and may be re-closed if the threshold is subsequently breached again; alternatively, schools remain closed for the duration of the epidemic.	Contact rates outside households reduced by specified compliance level (50-90%) for children, teenagers and one adult per household with children (children are "sequestered" in the home). Household contact frequencies doubled for these individuals. No empirical basis stated for these assumptions.	Reduced by 53-95% depending on compliance and R_0: for a given R_0, the reduction increases with the compliance level; for a given compliance level, the reduction increases as R_0 decreases. Only fairly weak dependence on rescinding threshold.	Reduced by 21-96% depending on compliance, rescinding threshold and R_0: reduction increases with increasing compliance, decreasing R_0 and decreasing rescinding threshold.	NA	NA

Davey et al (2008) [114]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
As [108], exploring a wider range of scenarios	”Scaled disease infectivity” 0.75 – 3.0 (a value of 1.5 is equivalent to R_0 ~ 2). Latent period = 1.25 days Infectious period = 2 days (including 0.5 days pre-symptomatic) Baseline cumulative clinical AR 14-46%, depending on infectivity	Introduced at cumulative incidence of 10, 30 or 100 diagnosed, symptomatic cases with compliance of 60% or 90%; maintained until the number of new cases in 7 days reaches 3 or 0. Schools can re-close if the threshold is subsequently reached again.	All school contacts reduced by 90%. Household contacts doubled for affected children. One adult stays at home in each household with a child <11 years. No empirical basis stated for these assumptions.	NA	Reduction ranged from 2% (for infectivity factor of 3.00) to 92% (for infectivity factor of 0.75).	NA	NA
Perlroth et al (2010) [125]							
As [108], with focus on economic aspects.	R_0 = 2.1 or 1.6 Mean infectious period 1.5 days Baseline clinical AR ~25% (if R_0 = 1.6) or ~35% (if R_0 = 2.1)	Introduced when 10 people (0.0001% of the population) have become symptomatic; schools reopen after 2 generation times have passed without new cases being diagnosed.	School contacts reduced by 90%, children’s household contacts doubled	NA	Reduced by 66% (if R_0 = 1.6) or 12% (R_0 = 2.1).	NA	NA

Compartmental models

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Roberts et al (2007) [126]							
SEIR model structured by location (household, schools, workplaces and community) but not explicitly by age. 47% of infections occur in households, 24% in schools, 18% in workplaces and 11% in community.	R_0 = 1.1, 2.0 or 3.0 Latent period = 1.2, 1.6 or 2.0 days Infectious period = 4.1 days Baseline clinical AR = 12%, 53% or 63%, for R_0 = 1.1, 2.0 and 3.0, respectively.	Schools closed immediately at start of epidemic	Elimination of transmission within schools; no effect on transmission in other locations. No empirical basis stated for these assumptions.	NA	If R_0 = 1.1, cumulative AR is close to zero (and R<1) if transmission in schools is reduced by 37%. Cumulative AR reduced by 25% or 12% if R_0 = 2.0 or 3.0 respectively.	NA	NA
Rizzo et al (2008) [115]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Age / location- and region-structured SEIR model including stochastic component; contact matrix defined by location (households, schools / workplaces, community). Age groups 0-2, 3-14, 19-39, 40-64 and ≥65 years. Population based on Italian census data (2001). School closures (for 3 weeks) incorporated together with closure of public offices (for 4 weeks) and public meeting places (for 8 weeks).	R_0 = 1.8 Incubation period = 1 day Infectious period = 3.9 days Baseline infected AR 35%.	2,4 or 8 weeks after the start of the pandemic	75% reduction in contacts among children and teenagers. Workplace closure reduces work-related contact by 16%, closure of public places reduces community contacts by 50%.	NA	Decreased by <1% if intervention implemented 2 or 4 weeks after start of pandemic, or by 2.6% if after 8 weeks.	NA	NA

Cruz-Pacheco et al (2009) [68]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
SIR model assuming homogeneous mixing, used to estimate change in contact rate with introduction of control measures, based on fitting to data from the 2009 pandemic in Mexico City.	Infectious period = 3 days. R_0 estimated as 1.72 and 1.27 before and after introduction of control measures, respectively.	Controls (including school closures as well as other measures) introduced ~1 week after start of outbreak, with or without relaxation ~2 weeks later.	Reduced by 27% (based on reported values of R_0 before and after introduction of control measures during the H1N1v outbreak in Mexico City) in a linear fashion over six days.	Peak prevalence reduced by 38% (from 10.5% to 6.5%) if control measures relaxed, reduced by 67% (to 3.5%) if not relaxed.	NA	Delayed by ~1 week.	Increased by 2-3 weeks if contact rate recovers instantaneously when controls are lifted. (Epidemic with no intervention lasts ~5 weeks)
Vynnycky & Edmunds (2008) [116]							
SEIR model with age-dependent contact rates based on several different WAIFW matrices and fitting to data from 1957 pandemic; stratified into <1, 1-4, 5-14, 25-44, 45-64, ≥65 year olds.	R_0 = 1.5-3.5 Latent period = 1.5-2 days Infectious period = 1.5-2 days	Schools and nurseries closed when overall disease incidence of 50, 100, 200 or 1000/100 000 per week; reopened when incidence declined below the threshold.	Decreased within-group contact rates for children aged 1-4 and 5-14 by 25-75%; no effect on other contact rates. Based in part on previous estimates of weekly transmission parameters for measles[170], which considered contacts between schoolchildren and compared school terms to school holidays.	Decreased by ~0-60%, depending on R_0, baseline mixing patterns, reduction in contacts and closure threshold. Greatest reductions associated with greatest reductions in contact, least assortative mixing patterns, lowest threshold for closure, and low values of R_0.	Decreased by <1% to ~24%, depending on R_0, baseline mixing patterns, reduction in contacts and closure threshold. Greatest reduction if assumed reduction in contact is large, mixing is least assortative, and R_0 is low.	Delayed by 1-2 weeks if R_0 = 1.8 or 2.5, contact reduction = 75%, and closure threshold = 1000/100,000 per week. Otherwise no effect.	Little or no effect for high R_0 or if reduction in contact is ≤50%. If R_0~1.8, increased by up to 70% and 40% if schools are closed early or late, respectively.
House et al (2011) [104]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
SEIR model stratified by age and risk group, based on population of England (data from 2008) and incorporating empirical contact data from Polymod. Percentage reduction in peak demand for intensive care unit beds in each hospital assumed to be equal to the percentage of children in that hospitals' catchment area who are affected by school closure.	R_0 = 1.1, 1.4 or 2.0.	Schools close for 1-4 weeks within half a day of the optimal time point for minimising peak incidence.	Age-specific changes consistent with Polymod data.	Reduced by 30-70%; size of reduction increased with increasing duration of closure and increasing R_0.	NA	NA	NA

Araz et al (2012) [103]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Age-structured SEIR model based on Texas population data.	Average latent period 3 days Average infectious period 6 days R_0 1.1, 1.3 or 1.5 in low transmission scenario, 1.5, 1.8 or 2.1 in high transmission scenario (results are combined for different R_0 values in each of these two scenarios)	Threshold prevalence of 0.5%, 0.8%, 1.1%, 1.4%, 1.7%, 2.0%, 3.0%, 4.0%, 5.0% or 6.0% in children aged 5-18 years. Closure lasted either for 1, 2, 3, 4, 8, 12 or 24 weeks, or until prevalence in 5-18 year olds had declined to 75%, 50% or 25% of the closure threshold.	Number of daily child-to-child contacts reduced by 80%. Contacts between adults and children either unaffected or reduced by 33%, depending on the direction of the contact. No effect on contact between adults. Assumptions based on Polymod contact data [145].	Peak prevalence reduced by ~80% (low transmission scenario) or ~88% (high transmission scenario).	For low R_0, reduction in cumulative AR was 5-94% in children aged 5-18 years and -37 to 78% in adults, depending on threshold and duration. Greatest effects with longest closures, but little additional benefit of closing for >12 weeks. If duration was over ~8 weeks, benefits were greatest with the lowest closure thresholds. For high R_0, reduction in cumulative AR was -3 to 86% for 5-18 year olds and -48 to 32% for adults.	Peak brought forward by ~60 days (low transmission scenario) or ~35 days (high transmission scenario).	Reduced by ≥75 days (low transmission scenario) or increased by ≥25 days (high transmission scenario).
Ghosh & Heffernan (2010) [171]							

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
SEIR model which also includes the effects of antivirals and vaccination. Infectious individuals are subdivided into those who are asymptomatic, untreated symptomatic, early treated symptomatic and late treated symptomatic; the recovered compartment is subdivided in an analogous way. Two pandemic waves are modelled with and without assuming that the first wave coincides with school summer holidays.	R_0 1.6 Latent period 3 days Infectious period 4.85 days	"School holidays are assumed to start 70 days after the first wave emerges and last approximately 60 days" (in the model without intervention, the peak occurs around day 60-70).	Transmission parameter reduced by 30%.	First wave: reduced by ~38% Second wave: reduced by ~95%	First wave: reduced by ~45% Second wave: reduced by ~77%	First wave: no effect Second wave: delayed by ~50-60 days	First wave: no effect Second wave: effect unclear.

Earn et al (2012) [10]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
SIR model with two age groups (5-18 year olds and others) fitted to pandemic H1N1 2009 data from Alberta, Calgary and Edmonton and used to predict the course of the epidemic if a planned school closure had not occurred. Transmission within each age group allowed to vary with temperature, absolute humidity and school closure.	R_0 1.72 – 1.78 (estimated value depending on dataset)	In the observed data, schools were closed for a planned holiday close to the beginning of the first wave; a model fitted to these data was used to predict how the epidemic might have developed had this school closure not occurred.	Transmission between children aged 5-18 years reduced by 63% (Calgary), 100% (Edmonton), 86% (Alberta), with no change in transmission amongst other age groups, based on fitting to the incidence data.	First wave, school aged children: reduced by ~70% in Alberta and Calgary, very little effect in Edmonton; Other ages: reduced by ~79% in Alberta, ~71% in Calgary, very little effect in Edmonton.	Calgary: reduced by ~28% Edmonton: reduced by ~35% Alberta: reduced by ~52%	Delayed by ~1 month	Duration of first wave increased by up to ~1 month

Bolton et al (2012) [127]

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Stochastic patch model describing transmission between aimags in Mongolia (not age-structured). Movement between aimags (provinces) based on national travel statistics (year of collection not stated).	Mean latent period 1 day Mean infectious period 1.5 days R_0 = 1.6 or 2.0. Baseline clinical attack rate 9.7%.	Schools closed at times ranging from week 0 to week 14 of the pandemic, for 2-12 weeks.	School closure reduces the effective reproduction number by a factor equal to the ratio of the attack rate in adults to that in children; this ratio was allowed to vary between 0.3 and 1.	"Modest impact" (not quantified).	Maximum reduction of ~11% (if schools closed for 4 weeks starting from week 5 and attack rate in children was 3 times that in adults). Smaller reductions were predicted as attack rates in adults and children became more similar and as school closure was delayed beyond week 5.	Delayed by up to two weeks.	NA

Other models

Population structure and contact rates	Infection parameter values	Threshold for closing schools and duration of closure	Assumed effects of school closure on contact patterns	Predicted effect on:			
				Peak incidence of infection	Cumulative AR	Time to peak	Duration of epidemic
Glass & Barnes (2007) [117]							
Household model describing transmission within and between households, in the community and schools / workplaces. Population based on Australian census data (2001).	R_0 = 1.5 or 2.5 Serial interval = 3.5 days Age-specific ARs calibrated to 1957 and 1968 pandemics.	Schools closed at start of outbreak, or at varying prevalence of infection in schoolchildren.	Elimination of transmission among children at school; increase in transmission between schoolchildren in households is in proportion to the extra time spent at home. Also allowed for one adult to stay home in every household with schoolchildren and no non-working adult. No effect on community mixing.	Decreased by ~10-70% depending on age-specific attack rates and R_0: greater reduction for lower R_0 and if attack rates are higher in children than in adults. Slightly greater reduction if parents stay home to look after children.	If schools are closed when prevalence in schoolchildren is 2%, decreased ~4-64% depending on age-specific attack rates and R_0: greater reduction with lower R_0 and if attack rates are higher in children than in adults. Similar results if schools reopen as the epidemic declines, as long as closure occurs when prevalence in children is <1%.	Delayed by 1-15 weeks, depending on age-specific attack rates and R_0: longer delay for lower R_0 and if attack rates are higher in children than in adults. Delay increased if parents stay home to look after children.	Increased by 20-75% (1-3 weeks) depending on age-specific attack rates and R_0: greater increase for lower R_0 and if attack rates are higher in children than in adults.