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Closure of schools during an influenza pandemic

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In response to WHO raising the influenza pandemic alert level from phase five to phase six, health officials around the world are carefully reviewing pandemic mitigation protocols. School closure (also called class dismissal in North America) is a non-pharmaceutical intervention that is commonly suggested for mitigating influenza pandemics. Health officials taking the decision to close schools must weigh the potential health benefits of reducing transmission and thus case numbers against high economic and social costs, difficult ethical issues, and the possible disruption of key services such as health care. Also, if schools are expected to close as a deliberate policy option, or just because of high levels of staff absenteeism, it is important to plan to mitigate the negative features of closure. In this context, there is still debate about if, when, and how school closure policy should be used. In this Review, we take a multidisciplinary and holistic perspective and review the multiple aspects of school closure as a public health policy. Implications for the mitigation of the swine-origin influenza A H1N1 pandemic are also discussed.

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Introduction

On June 17, 2009, 85 countries had officially reported 39 620 cases of swine-origin influenza A H1N1 virus infection to WHO,[1] including 167 deaths. On June 11, 2009, WHO raised the level of influenza pandemic alert from phase five to phase six, officially declaring that a pandemic had began while at the same time stating it was of moderate severity, noting that most infected people, including children, had a mild self-limiting disease.[2] In this context, health officials around the world are carefully reviewing their pandemic mitigation protocols. School closure (panel 1) is a non-pharmaceutical intervention often suggested for mitigating influenza pandemics.[3] In pandemic preparedness plans, rationales for school closures are that children are thought to be important vectors of transmission and more infectious and susceptible to most influenza strains than adults, and high contact rates in schools favour transmission. These are strong arguments in the current situation, where 60% of cases infected with H1N1 are 18 years old or younger[4,5] and many of case clusters have happened in schools. It is therefore hoped that closure of schools during the pandemic might break the chains of transmission, with the following potential benefits: reducing the total number of cases; slowing the epidemic to give more time for vaccine production; and reducing the incidence of cases at the peak of the epidemic, limiting both the stress on health-care systems and peak absenteeism in the general population, and thus increasing community-wide resilience.

Although some health benefits can be expected, there is still substantial debate about if, when, and how school closure policy should be used.[6–8] There is no consensus on the scale of the benefits to be expected,[6,9,10] and recent reviews highlighted the lack of evidence for social distancing measures such as school closure.[11,12] Even if benefits are substantial, they must be weighed against the potential high economic and social costs of proactively closing schools, which also can have negative effects on key workers since, for example, many doctors and nurses are also parents. Important operational issues related to school closures, though not impossible to overcome, need preparation (panel 2). Communication of the policy to the public also poses challenges, especially in a context where some countries (or even regions within a country) might close schools proactively, others perhaps only reactively, and some not at all. But since historical experience is that many schools close during pandemics just because of high levels of illness-related absenteeism, it would seem sensible for all countries to at least have plans for reactive closure.

School closure during a pandemic has been discussed in modelling studies,[6,10,13] in epidemiological studies,[12,14–19] and in work focusing more on economical, social, ethical, and public health features of the policy.[7,20–27] There is now a need to take a multidisciplinary and holistic perspective and review the multiple aspects of school closure as a public health policy in a comprehensive way, and to discuss the implications in the context of the current H1N1 pandemic. This Review contributes to that process.

Epidemiological evidence on health effect

Mathematical modelling of the effect of school closure

Mathematical modelling has been used to investigate the potential heath effects of school closure. However, although we discuss key conclusions and findings of pandemic models, it is not our intention to do a detailed review of the subject (Halloran and colleagues[28] review the findings of three models). In short, some models suggest that school closure combined with keeping all children at home might be sufficient to stop a pandemic,[6] whereas others found a marginal effect on epidemic size but a substantial reduction of peak incidence.[10] Those differences in model outputs are because of differences in modelling assumptions. For example, if it is assumed that 50% of transmissions occur in schools, a conclusion will follow that closure of schools will have an important effect on spread, especially if children can be kept apart outside of school. By contrast, if only 20% of transmissions happen in schools, a much smaller effect of closures is expected. Whether the 20% or 50% scenario is the most likely cannot be determined a priori (and this might vary between pandemics as well as between cultures or

Panel 1: **Definitions—types of school closure**

School closure
Closing of a school and sending of all the children and staff home

Class dismissal
A school remains open with administrative staff, but most children stay home

Reactive closure
Closure of a school when many children, staff, or both are experiencing illness

Proactive closure
Closure of a school or class dismissal before substantial transmission among the school children

Panel 2: **School closure operational issues**

- The potential need for local sensitivity in timing in larger countries as the pandemic spreads; it might not be necessary for all schools to close in all parts of a country at once, despite the communication and administrative advantages of doing so
- What should be the trigger for proactive closures?
  - The first case or outbreak involving the pandemic strain confirmed in a child or teacher
  - Outbreaks in neighbouring or nearby schools
  - What should be the trigger for reopening? Low levels of transmission in surrounding community?
- Recommended length of time of closure
- Sustaining teaching and learning over prolonged periods of closure
- Maintain contact with families and teachers—the advantages of class dismissal over school closures
- Anticipating group childcare arrangements
- Organised approaches to alternative childcare
- Sustaining social functions of some schools
- Complexities of school systems with state schools, independent schools, and faith-based schools and decisions on school closures often being matters for local not central government—ie, some countries find it much harder than others to have command and control relations with schools
- Potential loss of earning of parents who have to take time off work
- Establishing agreements between sectors (such as education and health) so that one does not undermine the other
- Communication issues of explaining different policies in neighbouring countries
- Should tertiary education be included?

settings—eg, urban *vs* rural). Modelling does not therefore provide primary evidence of the likely effect of school closure on transmission. Instead, it is necessary to carefully review what can be inferred from seasonal influenza epidemics and previous pandemics.

School closure in Hong Kong in March, 2008

In March, 2008, kindergartens and primary schools in Hong Kong were closed for 2 weeks after media reports of the deaths of two children, apparently from influenza.[15] Schools were closed just after the peak of the outbreak and a reduction in the number of cases at this time was seen (figure 1). A simplistic comparison of attack rates before and during school closure would conclude that the intervention had an important effect on spread. But in an influenza outbreak that has just peaked, such a reduction is expected even if there is no intervention. Figure 1 shows that the reduction after the peak in 2008 (when school closure was implemented) was essentially indistinguishable from that of 2007 (when schools remained open). Relying on the temporal pattern of the effective reproduction number (average number of people infected by a typical case) derived from sentinel surveillance data, Cowling and colleagues[15] detected no significant effect of school closure on influenza spread in this outbreak.

Teacher strike in Israel in 2000

In Israel, from Jan 16–28, 2000, during an influenza outbreak that started in the last week of December, 1999, a nationwide closure of elementary school classes took place because of a teachers' strike. From the large dataset of a health-care provider, Heymann and colleagues[16] compared the number of cases for the 2 weeks before the strike with the 2 weeks of the strike. They found 22% reductions in weekly numbers of physician visits and emergency department visits and 43% reductions in weekly numbers of respiratory tract infection diagnoses and of viral infections. However, as shown in the Hong Kong example, simple comparison of attack rates can give misleading conclusions because of the intrinsically non-stationary dynamics of a seasonal epidemic. However, in the Israeli example, the strike ended while the influenza outbreak was ongoing, and respiratory illness visit rates rebounded, suggesting that the strike likely had an effect on spread. Further comparison with other years would be useful to assess the exact effect of school closure in this outbreak.

School holidays in France, 1984–2006

A recent study analysed the timing of holidays and 21 years of surveillance data on influenza-like illness from France.[14] There are three holiday zones in France with deliberately different holiday timings between the zones. Comparing influenza-like illness incidence in the different zones as a function of whether zones are on holiday allows the effect of school holidays on transmission to be inferred.

The study used sequential Monte Carlo Markov chain methods to estimate the effect of holidays on the way individuals mix with each other. Holidays substantially affect the contact pattern of children—on average, children reduce their contacts with others by 25%. But no substantial effect was detected on the contact pattern of adults.

Using this characterisation, comparison of epidemics simulated for a typical timing of holidays, and under the assumption that schools were always open, revealed that holidays prevent about one in six seasonal influenza cases (ie, 16–18% more people would be infected with

seasonal influenza each year if schools were permanently open).

Extrapolating to the pandemic context (ie, in the absence of pre-existing immunity), if schools were closed proactively, the analysis predicted that reductions of 13–17% in the total number of cases could be expected (ie, one in seven cases of influenza prevented) but with larger reductions in peak attack rates (38–45%).

However, the limits of extrapolating from data on seasonal influenza to pandemic influenza should be emphasised. In particular, the French dataset measures the effect of holidays on transmission. During holidays, schools are closed, but there are a lot of other behaviours that are not associated with school closure (eg, people go on vacation, go abroad, celebrate Christmas, etc). Contact patterns during holidays might therefore be more distorted than would be seen during school closure alone. If schools are closed for a long period outside holidays, contact between children might increase in other settings. For example, children might mix more in their households and neighbourhoods. It is also possible that working parents would recreate school structures during a period of extended school closure (eg, one parent takes care of a group of children one day and another parent the next day, to reduce the effect of childcare needs on working patterns).

The analysis of the French data predicts that such compensatory behaviours could largely eliminate any reduction in cumulative and peak attack rates resulting from school closure. What children do when schools close is therefore crucial to the health effects of school closure. If schools close, it will be crucial to communicate the importance of keeping children somewhat isolated. The severity of a pandemic is likely to influence compliance with such requests.

School closure in the France during the 1957 pandemic

School closure was done in a piecemeal way in different areas of France in the 1957 pandemic. A historical review of 1957 French newspapers[29] shows that, at the time, public health officials were worried that closure of schools might increase anxiety and create a crisis. Decisions to close individual schools were delayed, often until after 50–75% of children had been ill. Decisions were local and there was a lack of national consistency because of a lack of a clear and simple strategy and the reluctance to implement such a measure. Overall this late intervention was judged to be ineffective at the time.

1918 influenza pandemic in US and Australian cities

Various non-pharmaceutical interventions were imposed by the authorities in US cities in the 1918 influenza pandemic. These included school closure, but often also included some combination of closing churches, banning mass gatherings, mandated mask wearing, case isolation, and disinfection and hygiene measures. The type and timing of the interventions varied by city. Three research groups investigated if those variations could explain observed variations in the peak and cumulative excess mortality rates between cities.[17–19,30]

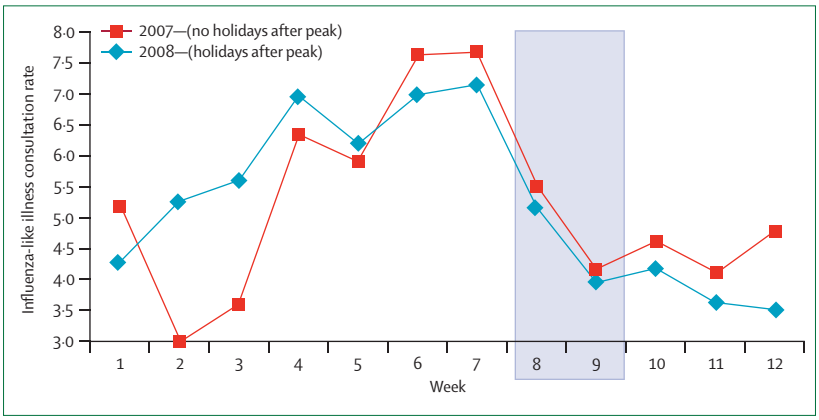

Figure 1: **Influenza-like illness consultation rate in Hong Kong in 2007 and 2008**
In 2007 (blue line) schools remained open after the peak and in 2008 (red line) they were closed just after the peak (blue rectangle).

Although the studies relied on different datasets (17 cities in two of the studies[18,19] and 44 cities in one[17]) and different methods, key findings were remarkably consistent between the studies. The health benefits were positively associated with early and prolonged implementation. The interventions had a moderate effect on total mortality (perhaps reducing mortality by 10–30%) with larger reductions in peak mortality (around 50% in some cities).

Because school closure was done in combination with other interventions, it is not possible to estimate the specific effect of school closure. It is only possible to note that combinations of non-pharmaceutical interventions including school closure and public gathering bans seemed to have the most substantial association with reductions in mortality,[17] but in some cities where schools were closed, the reduction in the total number of deaths was estimated to be as little as 10%.

Caley and colleagues[31] did a similar analysis for the 1918 pandemic in Sydney, Australia, and estimated that the public health measures made in that city (including school closure) might have reduced cumulative attack rates by up to 38%.

Severe acute respiratory syndrome in Hong Kong in 2003

During the 2003 severe acute respiratory syndrome outbreak in Hong Kong, various types of social distancing occurred—some as a result of government mandate but much because of public concern about the infection. Schools were closed, mass gatherings stopped, masks were often worn in public, and people stayed at home as much as possible. During this period, levels of laboratory-confirmed influenza and other viral respiratory pathogens were unusually low compared with the preceding 5 years, despite an increase in the number of specimens taken.[32] However, as for the 1918 pandemic studies it is impossible

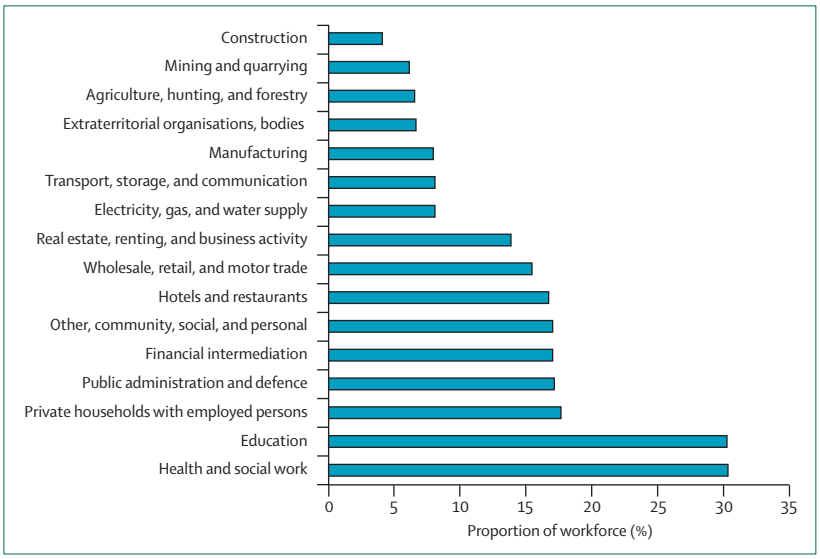

Figure 2: **Proportion of the UK workforce likely to be the main caregivers for dependant children by sector[25]**

to disentangle the effect of school closure from other measures.

Social and economic effects of school closure

Economic cost

Sadique and colleagues[25] estimated the potential economic effect of school closure in the UK. The main cost of school closure is because of absenteeism of working parents who have to stay home to take care of their children. This study found that overall about 16% of the workforce is likely to be the main carer for dependent children and therefore likely to be absent from work if schools are closed, with important variations between sectors (figure 2).[25] They also estimated that the intervention would cost between £0·2 billion and £1·2 billion per week, with the total cost of a 12-week school closure in the range 0·2–1·0% of gross domestic product (GDP).[25]

Sander and colleagues[26] used a microsimulation model to assess the economic effect of pandemic mitigation strategies (including full targeted antiviral prophylaxis, prevaccination, and school closure) in the USA. Under the assumptions made in their simulation model[33] and assuming 2·5 person days per week time loss for affected households and 5 days per week for teachers during school closure, they estimated a high economic cost of school closure (about US$2·7 million per 1000 population or 6% of GDP) and that strategies involving school closure would be between 14 and 21 times as costly as intervention strategies with antiviral drugs or prevaccination alone. Nevertheless, they concluded that, because of the further benefits in terms of health outcomes, combining school closure with other interventions might still be cost-effective from a societal perspective.

Source of income and job security

Parents who stay home during a school closure might be concerned about job security and maintaining their source of income.

In North Carolina, USA, schools were closed for 10 days during an influenza epidemic. A survey was done to assess how families responded to the school closure.[23] In this rural area where more than 50% of households have at least one adult that does not work outside the home or can work from home, the intervention caused little disruption, with only 10% of the households reporting having to make special childcare arrangements. Of course, the outcome would likely have been different if the proportion of working parents were as high as it is in many urban settings. Also there will almost certainly be differences in how parents respond to school closure lasting 1–2 weeks versus the 2–3 months that could be needed with proactive closure (panel 1) in a pandemic.

In a survey of a representative sample of 1697 American adults, Blendon and colleagues[21] found that, if schools were closed for 3 months, 86% of 634 households with at least one child and one employed adult reported they could arrange care so that at least one employed adult of the household could go to work.

Social justice and ethical issues

Berkman[20] discusses the adverse social consequences of a school closure policy and the ethical issues this raises. In many industrialised countries, social programmes targeting underprivileged children rely on school facilities. For example, in 2004 in the USA, the national school lunch programme and the school breakfast programme delivered daily meals to 29·0 million and 8·9 million children, respectively; half of the lunches served were free and an additional 10% were served at a reduced price.[20] Closing schools without preparation would interrupt those programmes, with adverse consequences for vulnerable children and families. In the American survey,[21] 25% of 664 adults who had major responsibility for children 17 years old or younger reported that a child in their household gets free breakfast or lunch at school or daycare. 34% of these 166 recipients of free meals said that not getting them during a 3-month closure would be a problem. Hence, in areas of the USA where schools have such extraeducational social functions, planning is being made to ensure the continuity of these services, and the term class dismissal is preferred to school closure (panel 1).

Berkman also discusses the risks associated with so-called self-care, defined as leaving a child in his or her own care or in the care of a sibling younger than 13 years old.[20] Self-care has been associated with risk behaviours including increased adverse peer pressure, underage drinking, and drug use. Some studies have found that, despite children being poorly equipped to care for themselves, parents overestimate their child's ability to self-care.[20] Children left in self-care, often from low-

income households, suffer from more behavioural and social problems.[20] Furthermore, studies of education performance show that declines after the long summer holidays are largest for children from poor and minority backgrounds.[20] The same type of social inequality should be expected after prolonged school closure during a pandemic.

Households with a low income or from minority groups are particularly exposed to serious financial problems if schools are closed for a prolonged period. For example, Blendon and colleagues[21] found that 93% of 91 low-income households (less than $25 000) would have serious financial problems if they had to stay home for 3 months, as opposed to 64% for 406 high-salary income households ($75 000 or more). The proportion drops to 84% and 37%, respectively, if they had to stay home for a month.

Effect on the health-care system

A concern is that, for many countries, school closure might be particularly disruptive for health-care systems. This is because women often represent an important proportion of this workforce. Sadique and colleagues[25] found that, in the UK, an estimated 30% of the health and social workforce is likely to be the main carer for dependent children (younger than 16 years) in the home (as opposed to a mean of 16%, in the British workforce). In a survey, Dalton and colleagues[22] found that 38% (33 of 72 people surveyed) of the Australian public health workforce might be absent from work if schools closed during a pandemic. A survey of over 5000 hospital doctors and nurses by the UK Department of Health found that 77% of respondents were women (78% of UK doctors and nurses are women), 50% of respondents had a dependent child under 16, and 21% of respondents reported they would likely be absent from work if schools closed during a pandemic. The health and social workforce in Sweden shows similar demographic features: women represent 83% of this workforce, 41% of which have at least one dependent child under 16 years (table).

During a pandemic, school closure will not be the only cause of absenteeism. Sadique and colleagues[25] estimate a value for peak absenteeism in the health-care workforce as high as 45% (30% due to school closure, 10% due to sickness in staff, and 5% for other reasons)[25] so that important disruptions in service provision could be expected. For health-care systems that are run with very high levels of bed occupancy in a typical winter, even a small absence of health-care staff might have immediate and deleterious effects. More detailed assessments of the effect on key workers and health care in different countries should therefore be a priority, and the potential benefits of school closure for health care (ie, the possibly substantial reduction in peak demand) weighed against the disruption caused by absenteeism.

	Number with dependent children (% of total)			Total
	Younger than 6 years	6–12 years	Younger than 18 years	
Women	89 714 (15%)	119 904 (20%)	248 746 (42%)	587 048
Men	18 477 (16%)	18 835 (16%)	40477 705 (35%)	115 727
Total	108 191 (15%)	138 739 (20%)	289 451 (41%)	702 775

Source: National Statistics Office of Sweden.

Table: **Number (%) of health workforce in Sweden with children**

Implementation, communication, and interoperability

Three historical datasets (1918 US cities, 1957 French pandemic, and 2008 Hong Kong outbreak) highlight the crucial importance of the timing of an intervention. For the Hong Kong 2008 and French 1957 pandemic examples, the intervention inevitably failed to have a detectable effect because of its implementation very late in the outbreak. Modelling suggests that if schools can be closed before 1% of the population get sick, the effect of the intervention remains close to maximum.[28]

The desirability of closing schools at an early stage of local epidemics raises several questions about implementation and triggers (panel 2). One option would be to implement local reactive school closure—closing schools when a transmission of the pandemic strain is detected in the school or in a particular area. One risk for such an approach is that local surveillance might be lacking in sensitivity or promptness, meaning schools are closed too late. False positives might also be an issue, given surveillance of influenza-like illnesses will probably not be able to distinguish between pandemic influenza and other respiratory disease outbreaks. The second option is synchronised national (or, in larger countries, regional) closures that have the benefits of consistency and simplicity; they can rely on national surveillance systems that are expected to be more robust than local mechanisms. The health effect of national or regional closure is expected to be more substantial than that of local closure, but with a higher economic and social cost, since schools might be closed for longer and in areas with low local incidence. This is a particular issue with the highly heterogeneous pattern of the H1N1 pandemic so far, even within a single small country such as the UK.[34]

The trigger for closure (whether local or national) is also crucial. Use of a trigger based on school absenteeism rates might lead to closure occurring only late into the epidemic, limiting any effect on spread. Even relying on sentinel surveillance of influenza-like illnesses might lead to decisions being made too late, given the limited sensitivity of such surveillance and the background incidence of non-influenza related illnesses. Arguably, triggers based on virological identification of the first few hundred pandemic influenza cases identified in a country might be the most reliable, but as the H1N1 pandemic is

demonstrating, seasonal variation in influenza transmission could mean that such a sensitive trigger might lead to schools being closed for months. Even if triggers could be identified that took account of seasonality in the intensity of transmission but reliably initiated closure when only a one or two percent of the population had been infected (needed for maximum effect), schools could still end up being closed for 12–16 weeks.

The decision to reopen schools might be equally challenging. An important limitation of social distancing measures is that their effect stops as soon as the intervention is relaxed. There were various examples in US cities in the autumn of 1918, in which the lifting of interventions was associated with a second peak in the outbreak. Lifting of non-pharmaceutical interventions therefore requires some assurance that population herd-immunity has been reached—whether through immunisation or natural infection. Cross-sectional seroprevalence surveys would be the most reliable method of determining if the population has sufficient collective immunity, but proxy measures might be able to be identified. Another possible rule-of-thumb is to reopen schools only once children (or the general population) have been immunised with a pandemic vaccine.

The 1957 French example highlighted how lack of clarity or consistency in the decision process could lead to ineffective policy. In European countries, the organisation of education systems is variable. A few have centralised command and control systems that would allow central decisions, but many have highly decentralised systems. The USA also has localised decision making on education. Establishing national policies in such countries poses challenges.[24]

Reactive closure of schools can be seen as inevitable because of staff or pupil absenteeism resulting from illness or fear of infection. Plans at the national, local, and school levels are therefore needed irrespective of whether proactive closure is planned. Equally, all families with school children should be encouraged to think what they would do if schools closed for an extended period (panel 2). The unintended social consequences of school closure would also be minimised if countries carefully assessed how their legal and welfare systems, plus the charitable sector, could help and protect workers who cannot attend work because of school closure.

Educational continuity is a further issue. In the American survey,[21] if schools were closed for 3 months, 95% of 610 adults with major responsibility for children aged 5–17 years would be willing to give school lessons at home, and 47% thought they would need a lot or some help. France, which plans to close schools in a pandemic, intends to use TV and radio to broadcast lessons, coupled with direct interaction between pupils and teachers by telephone or internet communication.[35]

In today's worldwide, multisource, constant news media, both the public and the authorities in one area will be very aware of developments in other regions and countries. Information on deaths among children and whether proactive or reactive school closure is being used in countries that are affected early will undoubtedly be reported. Given that the public and media see threats to children's health with particular concern, interest is likely to be intense as to whether, why, and when schools will be closed in European countries. Use of school closure as a public health policy also gives the implication that school attendance poses a risk, so it is likely that some parents will think about withholding their children from school irrespective of official policy. In addition, some teachers might also fear for their health, and head teachers and school administrators will be seeking advice. Good, consistent communication will therefore be essential.

A particular issue arises over interoperability—recognising how actions in one community might affect another and trying to minimise negative effects of regional differences in policy. For example, if one educational authority announces that it is closing schools, this will inevitably affect neighbouring areas, especially without planning or prior warning. An additional complication in Europe is that policies that might be desirable or feasible in one country might not be possible in others (panel 2). Management of these issues requires careful advance planning.

Conclusions and implications for the mitigation of the H1N1 pandemic

In this Review, we have taken a multidisciplinary and holistic perspective in reviewing school closure as a public health policy in an influenza pandemic.

Two historical studies (holidays in France and the experience of US cities in 1918) provide information on the likely maximum health effect of school closure in past epidemics and pandemics, each of them come with their own limitations. Those two datasets suggest that, in an optimistic scenario, closure of schools during a pandemic might have some effect on the total number of cases (maybe a 15% reduction), but cause larger reductions (around 40%) in peak attack rates. However, this reduction will be substantially undermined if children are not sufficiently isolated or if the policy is not well implemented. The 2008 Hong Kong outbreak, the French experience during the 1957 pandemic, and the 1918 pandemic records in some US cities show that a failure to have any discernible effect is possible, especially if decisions come too late. It is also possible to hypothesise perverse effects such as an increase in mortality in older people if they are engaged to care for children when schools close.

However, estimates of health effect derived from past pandemics and epidemics are not necessarily relevant for H1N1. Indeed, comparison of the 1918, 1957, and 1968 pandemics shows that there is no such thing as a standard pandemic. On the bases of illness attack rates and reports

of illness in children (figure 3), it seems that school closure might have had a substantial effect in 1957 when much transmission took place among children, some effect in 1918, but a lesser effect in 1968 when illness attack rates were similar among children and adults. In the early stage of the H1N1 pandemic, the large proportion of children among cases so far,[4,5] and the large number of case clusters in schools strongly suggest that the reduction in the number of cases because of school closure in this specific pandemic will be stronger than would be expected from observations based on seasonal influenza.[14]

The intervention has a high economic cost, with two estimates available in the published work: up to 1% of British GDP for a 12-week school closure[25] and 6% of US GDP.[26] School closure also raises a range of ethical and social issues, particularly since families from underprivileged backgrounds are likely to be disproportionately affected by the intervention.

In a severe pandemic, countries might be ready to pay those high social and economic costs to benefit from the potential reduction in cases. But they should very carefully consider the effect that the intervention might have on key workers, education, and on crisis management capacity. For example, school closure might lead to important reductions in the peak incidence of cases, therefore reducing health-care system burden when the stress on the service is maximum. But this should be weighed against the potential disruption caused to the health services because of increased absenteeism of the workforce.

The decision to close schools must be made on the basis of the severity of the pandemic. This is illustrated by the recommendations that have been made by the US Centres for Disease Control and Prevention (CDC) which contrast with earlier recommendations.[39,40] On the basis of information that many cases in the Mexican epidemic had severe illness, the CDC initially recommended school closure as an option to lessen the risk of infection from a potentially severe disease. However, as estimates of severity were revised downward, recommendations were changed and the early identification and isolation of ill students and staff became the primary method to reduce the spread of influenza in schools.[40] The use of stringent and costly measures such as school closure should indeed be based on age-specific estimates of severity and local morbidity indicators. It is important to emphasise again that the WHO phases are not an indication of severity (phase six only means that there is a sustained spread of the virus in different continents); WHO now makes parallel statements on severity and geographical spread.[41,42]

School closure will of course not be the only intervention used in a pandemic; it should be considered in combination with other interventions that are available, such as antiviral drugs, vaccines, and other non-pharmaceutical interventions. Modelling suggests that, in certain circumstances, the combined effect of a set of

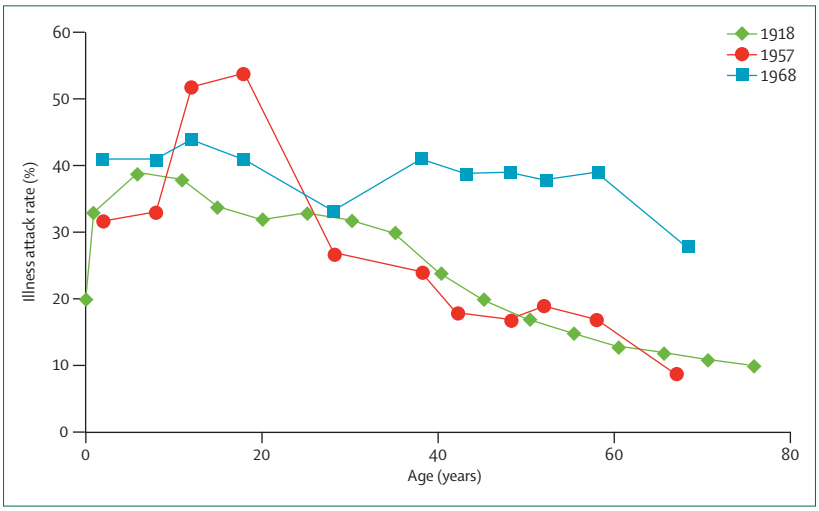

Figure 3: **Illness attack rates in 1918, 1957, and 1968 pandemics**
1918[36]—transmission in children and young adults. 1957[37]—transmission focused especially in the school-age population. 1968[38]—transmission across all age groups.

interventions might be larger than the sum of the individual impacts.[28] This can happen when the different interventions are complementary, targeting different places or groups of individuals (eg, school closure and banning of mass gatherings and closure of selected workplaces). However, if the interventions target the same place or group of individuals, then the combined effect might be smaller than the sum of the individual impacts. For example, if children are vaccinated, the additional benefits gained by closing schools might be very small. These complexities mean that predicting the effect of combined interventions is challenging, and modelling has an important role in assessing likely impact. But it is important as new data become available on the effectiveness of individual interventions—such as the effect of school closure[14]—that model parameters and predictions are updated.

The H1N1 pandemic could become more severe, and so the current cautious approach of not necessarily recommending school closure in Europe and North America might need reappraisal in the autumn. Another important uncertainty for pandemic planning is that individuals are likely to change their behaviours during a pandemic in a way that is difficult to predict. There is, for example, evidence that people reduced their contacts during the 1918 pandemic when mortality was high.[18,31] The ways children mix with each other during a prolonged school closure remain a key uncertainty, likely to be influenced by the severity of the pandemic.

This Review highlights that there are still many uncertainties about the health, economic, and social implications of closing schools to mitigate an influenza pandemic. Research priorities to reduce this knowledge gap include:

- Detailed outbreak investigations in schools (before, during, and after closure) along with detailed follow-

Search strategy and selection criteria

We did searches on PubMed and ISI Web of Knowledge 4.0 over all dates (Jan 1, 1950, to Dec 1, 2009) covered by each search engine for papers written in English. We searched for the following terms: "influenza" and ("non-pharmaceutical" or "community mitigation" or "social distancing" or "school closure"). All abstracts were read by SC. Papers were selected for review if they presented primary data on health, economical, logistical, social, ethical, or policy aspects of school closure. The reference lists of selected papers were also screened for papers missed in the web search query and a few additional studies were added by the authors. All papers selected for review were read by SC. 75 papers were found by the web search and nine were added by the authors. Out of those 84 papers, 19 contained primary data providing information on school closure as a public health policy.

up of households of students. Such studies will provide information on the health benefits for students and their families and allow better understanding of transmission dynamics within the school and school–household interactions. Outbreaks that are investigated are usually atypical, in the sense that they are expected to be larger than an average school outbreak. Caution is therefore necessary when extrapolating from those outbreaks to nationwide estimates. For this reason, a meta-analysis will be particularly useful.

- As part of the same studies, the economic and social impact of the closure on households should be established. Linking the epidemiological and economic components of household questionnaires will allow investigation of the cost-effectiveness of the intervention.
- Collecting data on activities and interactions with other children during school term and during school closure. So far, the absence of such data reduces our ability to assess the effect of school closure on influenza spread, namely we do not know how mixing patterns of children outside school are modified when schools close (so-called compensatory behaviours).
- Assessing the effect of school closure on transmission in the wider community (ie, not just children and their families). This will be more challenging since it will require collecting good incidence data at a geographical resolution that matches the catchment area of the schools. Such spatial resolution cannot be achieved with traditional surveillance networks, so non-conventional approaches (such as polls organised by phone or on the web) will have to be considered.
- There is also a need to refine our understanding of the implications of school closure for health-care and other essential services. This could be done through surveys of health-care managers and workers.

Contributors

SC did the systematic review and drafted the paper. All authors commented and edited the paper. CW contributed to the epidemiological components of the Review, AT to the economical, social, and policy components, GS to the educational and policy aspects, and BD to the communication components of the Review. SC, NMF, and AN contributed to all components of the review and designed the original workshop.

Conflicts of interest

SC has received consulting fees from Sanofi Pasteur MSD for the modelling of varicella zoster virus, and lecture fees from Roche. NMF has received consulting fees from Serco, advisory fees from Novartis, Roche, and GlaxoSmithKline; and lecture fees from Roche for a lecture given in November, 2006. The other authors declare no conflicts of interest.

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