Expected impact of school closure and telework to mitigate COVID-19 epidemic in France

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SUMMARY

With COVID-19 now a global pandemic, several countries face sustained and extensive epidemic spread in their territories. Forty-nine countries have announced or implemented school closures to mitigate the epidemic, 30 of which are nationwide (including China, Republic of Korea, Japan, Italy, France). French authorities announced on March 12, 2020 that school closure will be implemented nationwide starting March 16. These measures have been evaluated for seasonal or pandemic influenza, but their effectiveness for COVID-19 remains unclear. Focusing on the 3 regions in France reporting more than 300 confirmed cases (as of March 13, 2020) and showing an increase in the influenza-like-illness incidence from sentinel surveillance (Île-de-France, Hauts-de-France, Grand Est), we evaluate the impact of school closure and telework through a stochastic age-structured data-driven epidemic model. The model is based on demographic and social contact data between children and adults for each region, and is parameterized to COVID-19 epidemic, accounting for current uncertainties in the relative susceptibility and transmissibility of children. Numerical results show that school closure alone would have limited benefit in reducing the peak incidence (less than 10% reduction with 8-week school closure for regions in the early phase of the epidemic). When coupled with 25% adults teleworking, 8-week school closure would be enough to delay the peak by almost 2 months with an approximately 40% reduction of the case incidence at the peak. This is critical to reduce the burden on the healthcare system in the weeks of highest demand. Moderate overall reduction of the final attack rate (15%) would also be achieved. Results across regions are qualitatively similar, with differences in predictions due to different age profiles, the current epidemic situation, and epidemic growth. Different hypotheses on children

susceptibility and infectivity relative to adults show similar epidemic and intervention outcomes. Explicit guidance on telework and interventions to facilitate its application to all professional categories who can adopt it should be urgently provided. These findings help informing countries to prepare for effective COVID-19 epidemic mitigation.

INTRODUCTION

On March 11, 2020, the World Health Organization declared COVID-19 a global pandemic[1]. Several countries worldwide face active virus circulation in certain regions of their territory. Social distancing has become the priority in order to delay and mitigate the epidemic, reduce its impact on the population and on national healthcare systems[2].

School closure is often invoked as a non-pharmaceutical intervention to achieve these objectives[3]. Children may act as key drivers for disease spread, as they mix at school with high rates[4]. Closing schools may then reduce disease propagation in the community by breaking important chains of transmission[5,6]. Delay of the peak and reduction of incidence following implementation of school closure have been evaluated for influenza epidemics and pandemics[6]. Several countries adopted this measure in response to pandemic influenza A (H1N1) in 2009[7–13]. A total of 49 countries are currently implementing nationwide (30 countries) or localized (19) school closure in reaction to COVID-19 epidemic spread[14]. The French Government announced on March 12, 2020 that nationwide closure of schools and universities will be implemented starting March 16[15]. The effectiveness of this measure for COVID-19 is however still debated due to the unknowns on the role of children in the epidemic[16].

Here we use a stochastic age-structured epidemic model integrating data on age profile and social contacts of individuals to evaluate the effectiveness of school closure. The model was previously validated on seasonal influenza epidemics and used to assess the role of regular school closures due to holiday periods at a country scale[6]. We adapt the model to consider a SEIIR compartmentalization parametrized on COVID-19 disease based on current knowledge. We study the effect of school closure in the three regions in France that are currently most affected by the COVID-19 epidemic – Île-de-France, Hauts-de-France, Grand Est. In addition to school closure, we also consider telework that was recommended by authorities as a social distancing measure[15].

METHODS

We considered a stochastic age-structured epidemic model based on demographic and age profiles of the regions of Île-de-France, Hauts-de-France, Grand Est[17] (Figure 1). These regions were chosen as they reported more than 300 confirmed cases as of March 13, 2020[17] and showed a considerable increase of influenza-like-illness cases reported by sentinel surveillance in the last two weeks[18,19] (Figure 1). This indicates that COVID-19 may be actively circulating in these territories.

Mixing. Two age groups are considered, ≤18 years old, and above. We used social contact matrices measured in France to account for the mixing between individuals in these two age groups and accounting for the place where these contacts occur (household, school, workplace, other)[20]. More precisely, we consider a calendar with a weekly rhythm (Monday-Friday, followed by the weekend) whose contacts depend on the opening / closure of the schools[6] and the %of individuals performing telework. When schools are opened, mixing is informed with the social contact matrix measured during the regular school term. When schools are closed, mixing is informed with the social contact matrix measured during holidays in France in a regular year (i.e. in absence of a health crisis). When telework is additionally considered (with schools open or closed), mixing accounts for the reduction of contacts that teleworkers would otherwise establish at workplaces.

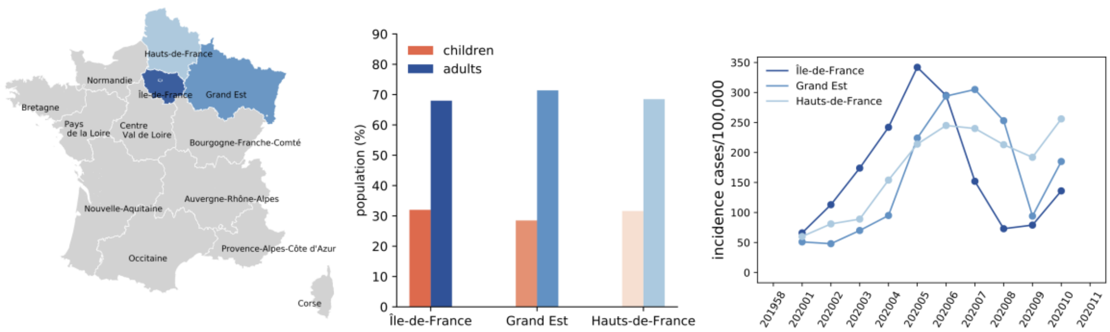

Figure 1. Regions considered in the study (left), associated age profile in the two classes (children and adults; center), ILI sentinel curves showing the increase in ILI case incidence in the last two weeks (right).

Compartmental model and transmission. Transmission dynamics follows a compartmental scheme specific for COVID-19 (Figure 2), where individuals are divided in susceptible, exposed, pre-symptomatic infectious, symptomatic infectious, and removed. The incubation period is set to 5.2 days[21] and the infectious period to 2.3 days (from the estimate of 7.5 days of serial interval[22]). Infectious individuals spend half of the infectious period in the pre-symptomatic compartment[23] and we assume that infectiousness is equal for both infectious compartments[24]. Transmission is calibrated on the exponential growth estimated in each region (Figure 1) – 0.67 for Île-de-France, 0.69 for Grand Est, 0.68 for Hauts-de-France – that is similar to the exponential growth estimated from the number of confirmed cases[17,19].

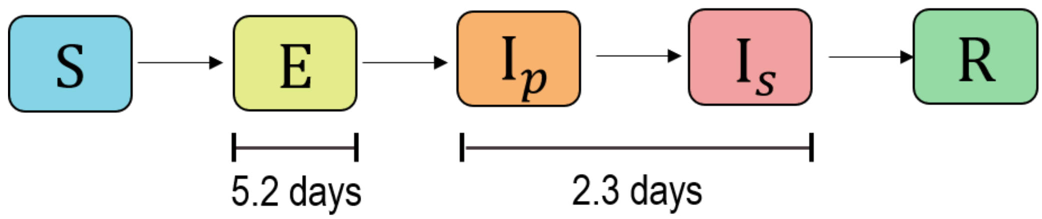

Figure 2. Stages of disease progression. S=Susceptible, E=Exposed, I_p=Pre-symptomatic Infectious, I_s=Symptomatic Infectious, R=Removed.

Role of children in the spread. Susceptibility and infectivity of children for COVID-19 are still unknown. We assume children relative susceptibility to be 0.2 and relative infectivity to be 0.5 (low susceptibility and moderate infectivity), compatible with outbreak data from China[25]. We also tested a scenario in which children have the same susceptibility and infectivity as adults (full susceptibility and infectivity).

Change of behavior due to illness. When adults become symptomatic, a fraction of them (55%) is assumed to change behavior due to their illness, based on Italian outbreak data[26]. Individuals reduce their contacts, similarly to what was observed during 2009 H1N1 pandemic[27]. We assume that children do not change behavior when ill, as they experience mild or no symptoms[28]. A scenario with no change of behavior in adults during illness was also tested.

Simulations, seeding, case underdetection. Île-de-France, Hauts-de-France, and Grand Est regions reported 577, 349, 699 confirmed cases as of March 12, 2020[17], respectively, but these numbers may suffer from substantial non-identification of cases[29]. We consider therefore a spreading scenario in each region by seeding the region with 4 times the number of confirmed cases, accounting for the largest estimate (75%) of case underreporting assessed during the initial phase of the outbreak in Italy[29]. In absence of case underreporting estimates for France, we consider a spreading scenario in each region seeded with 30 times the number of confirmed cases (97% underreporting).

Scenarios comparison. In each region, we compare a scenario with no intervention (baseline) with the scenarios implementing school closure starting on March 16, 2020 for a duration of 6, 8, 10, and 12 weeks. Six-week duration would correspond to closing school till the end of Spring holidays for regions in the zone C in France, that includes Grand Est and Hauts-de-France (Spring holiday in Île-de-France would end 1 week before)[30].

Scenarios are compared in terms of final attack rate, peak time, peak incidence.

In addition to school closure, we also consider that a given % of adult population would telework, thus reducing their contacts. In France telework is performed daily by 5% of the adult population[31] thus we consider 10%, 25%, and 50% of the adult population adopting telework. 50% is informed by data from participatory surveillance monitoring COVID-19 associated behaviors in France[32]. Telework is assumed to continue beyond the reopening of schools.

For each scenario, we perform 100 stochastic runs, median curves are displayed together with the associated 95% confidence intervals.

RESULTS

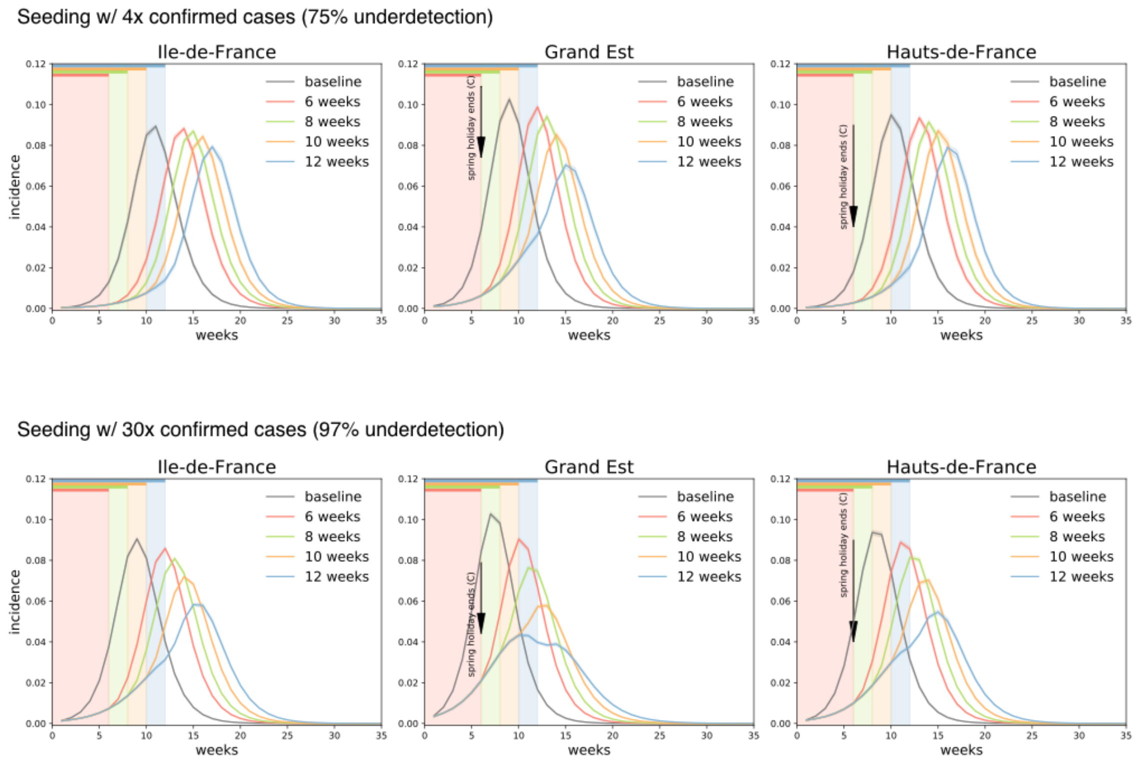

Figure 3. Incidence curves for the baseline scenario (no intervention, grey line) and the school closure scenarios of different durations (colored lines) for Île-de-France (left), Grand Est (center), and Hauts-de-France (right). The shaded areas indicate the time period in which the school closure is implemented (color coded as the corresponding incidence curves). The model is seeded with 4x the number of confirmed cases (75%underreporting, top) and 30x the number of confirmed cases (97%underrerporting, bottom).

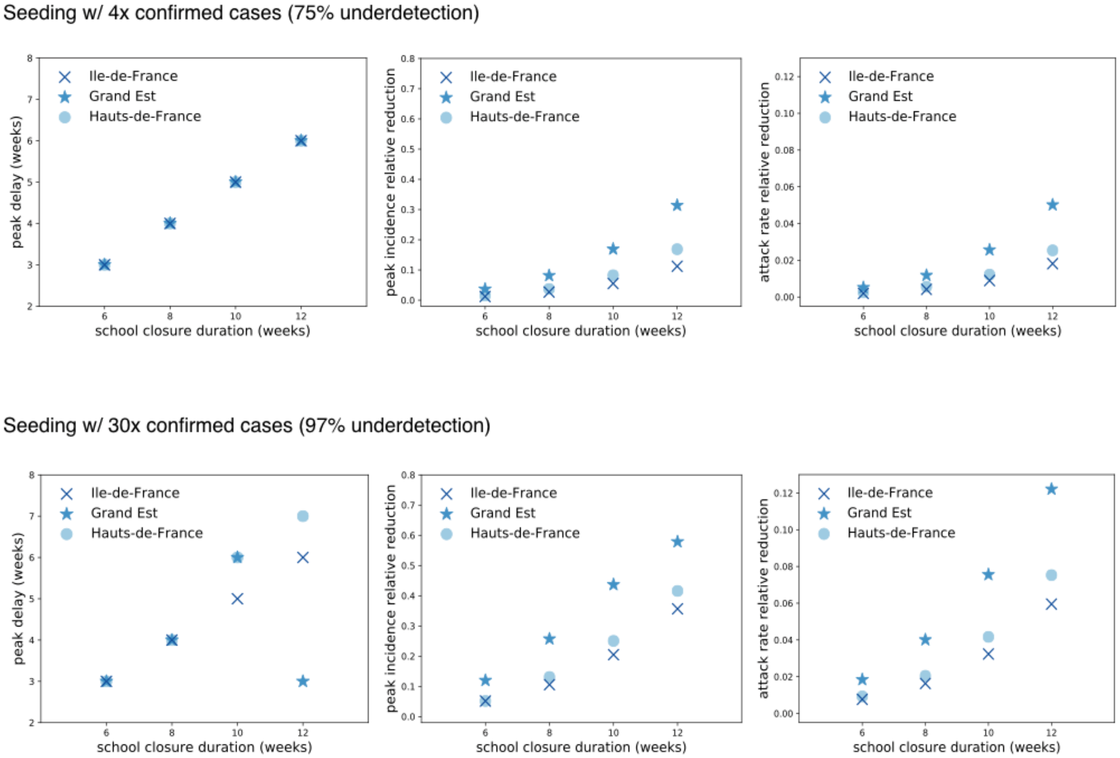

Figure 4. Summary results of the impact of school closure in terms of peak delay (left), relative reduction of peak incidence (center), relative reduction of epidemic size (right) as a function of the duration of school closure in the three regions. The model is seeded with 4x the number of confirmed cases (75%underreporting, top) and 30x the number of confirmed cases (97%underrerporting, bottom).

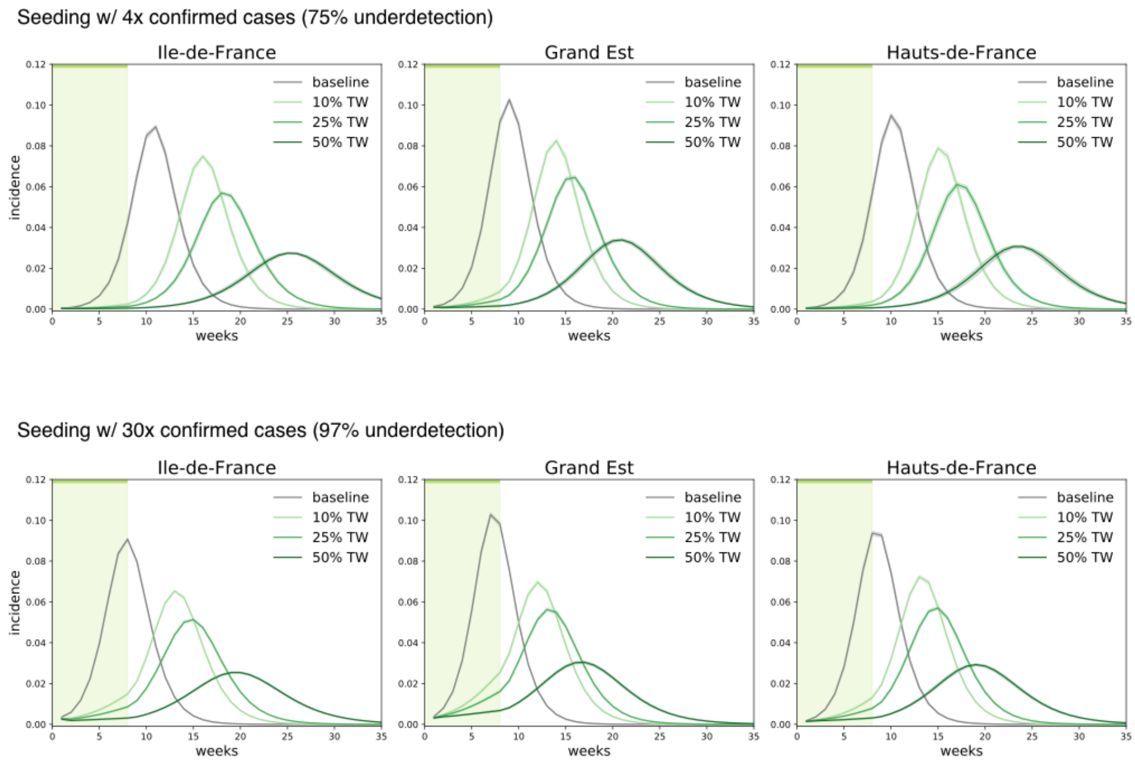

Figure 5. Incidence curves for the baseline scenario (no intervention, grey line) and the 8-week school closure scenario for Île-de-France (left), Grand Est (center), and Hauts-de-France (right), with 10%, 25%, and 50% of adult population doing telework (TW). The shaded area indicate the 8-week period during which the school closure is implemented. Telework continues after school closure. The model is seeded with 4x the number of confirmed cases (75% underreporting, top) and 30x the number of confirmed cases (97% underrerporting, bottom).

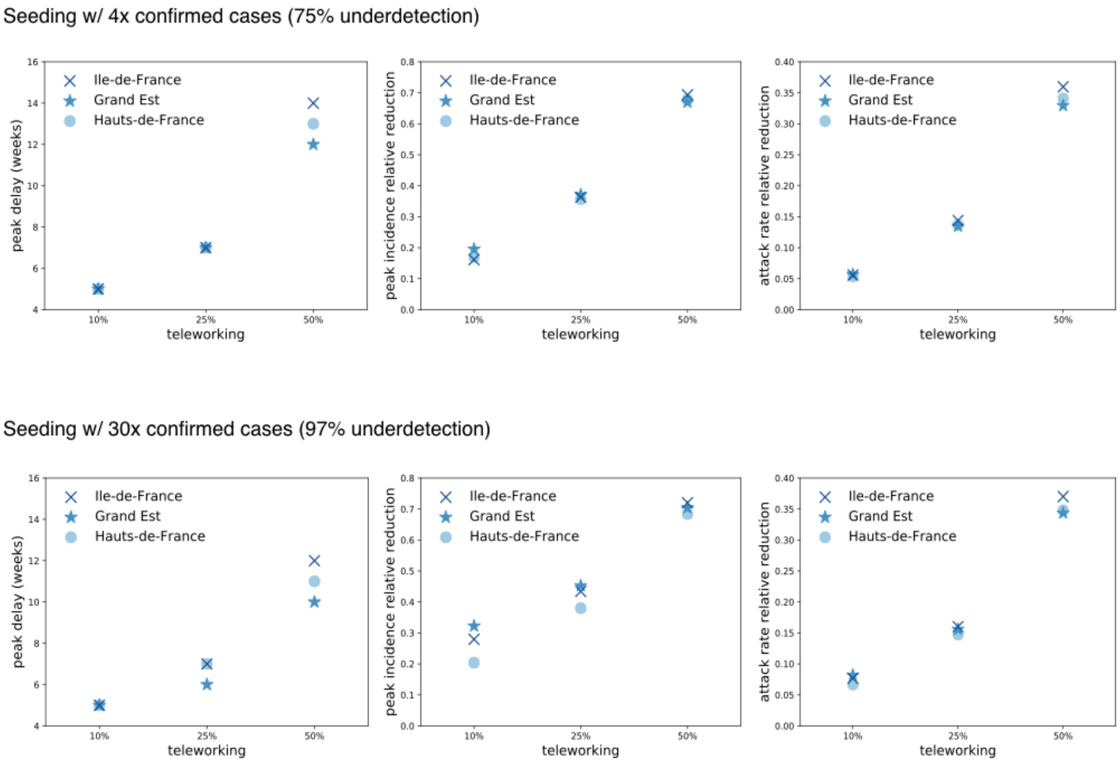

Figure 6. Summary results of the impact of 8-week school closure with telework for Île-de-France and Grand Est regions in terms of peak delay (left), reduction of peak incidence (center), reduction of epidemic size (right) as a function of the % of telework. The model is seeded with 4x the number of confirmed cases (75% underreporting, top) and 30x the number of confirmed cases (97% underrerporting, bottom).

Sensitivity

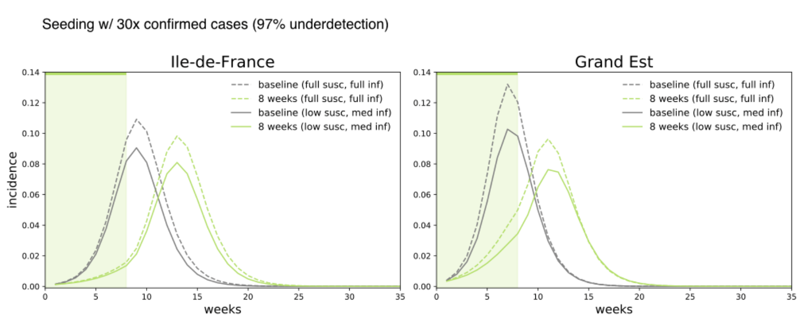

Figure 7. Impact of assumptions on relative susceptibility and infectivity of children compared to adults on the effectiveness of school closure. Only the baseline scenario (no intervention) and 8-week school closure scenario are shown for Île-de-France (left) and Grand Est (right) regions, comparing incidence results from low susceptibility and medium infectivity of children relative to adults (parameters used in the main results, continuous lines) with the case of full susceptibility and infectivity (i.e. sensitivity scenario with children and adults having the same susceptibility and infectivity, dashed lines). The model is seeded with 30x the number of confirmed cases (97% underrerporting).

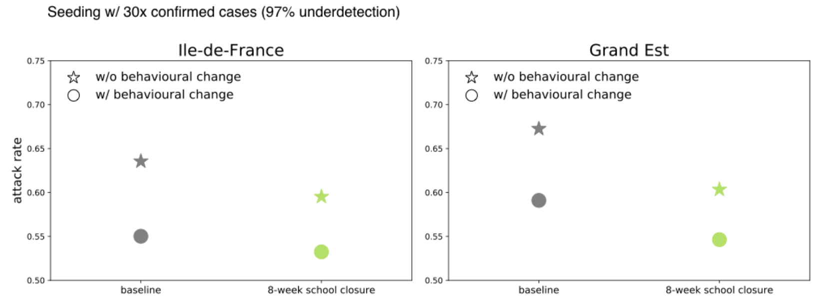

Figure 8. Impact of change of behavior of adults while ill on final attack rate. Only the baseline scenario (no intervention) and 12-week school closure scenario are shown for Île-de-France (left) and Grand Est (right) regions, comparing final attack rates from the scenarios with and without change of behavior in adults while ill. Differences in the attack rates across regions are due to different age profiles of the populations in those regions, epidemic contexts, and estimated epidemic growth. The model is seeded with 30x the number of confirmed cases (97%underrerporting).

KEY FINDINGS

- School closure as the sole mitigation measure will become effective in substantially delaying the peak (≥1 month) if it lasts ≥8 weeks. The benefit in reducing the peak incidence would however remain small if the region currently experiences the early phase of the epidemic (less than 10% reduction with 8-week school closure), and would be larger if the region is already in an advanced epidemic phase (e.g. about 30%reduction in the Grand Est region under the assumption of 97%underdetection of cases). When coupled with 25%adults teleworking, 8 weeks of school closure would be enough to delay the peak of almost 2 months with approximately 40%reduction of the incidence at the peak. Delaying the peak and reducing its magnitude are fundamental to reduce the burden on the healthcare system in the weeks of highest demand. Telework will also be critical in lowering the overall burden of the epidemic on the population at the end of the epidemic wave (15%reduction of final attack rate with 25% telework and 8-week school closure vs. maximum 4%reduction with 8-week school closure only). Explicit guidance on telework and interventions to facilitate its application to all professional categories who can adopt it should be urgently provided.
- The impact of mitigation measures is predicted to vary across regions. This is due to several factors. For example, regions may differ in their age profile, so that interventions targeting specific age groups (students, active adult population) will have different outcomes. Most importantly, the impact will depend on the current epidemic context. Grand Est region has the largest proportion of confirmed cases (0.013%compared to 0.006%for Hauts-de-France and 0.005%for Île-de-France, as of March 13, 2020) and the largest reported growth rate of cases across the three regions. School closure as a standalone mitigation measure is sensitive to the phase of the outbreak. With the school closure starting on the same date nationwide, its

effectiveness will depend on the epidemic phase each region is currently experiencing. The adoption of telework uniformize the impact of coupled mitigation measures across regions.

- Additional social distancing measures, including rigorous avoidance behaviors of individuals (avoidance of crowds, gatherings, distance >1m, etc.), coupled with strict hygiene measures (no-touch policy, hand-washing, etc.) are expected to increase the benefit gained with telework for the control of the disease spread and further reduction of the impact on the population. These actions are expected to be even more important given recent results on the long potential persistence of the virus on surfaces (72h) and its transmission by aerosol for multiple hours[33].
- Real-time evaluation of currently adopted measures in France, as well as lessons learnt from the experiences of other countries implementing stricter policies (e.g. closing commercial activities and forbidding all sport and leisure activities, as in Italy and Belgium) will become crucial in the next few weeks to inform interventions and recommendations adapted to the evolving epidemic situation in the country.
- If school closure is stopped too early, a rebound effect with an acceleration in the generation of new cases is likely to occur, as known from previous studies[6]. Here we assumed telework to last for the full simulation; its feasibility still needs to be assessed. If telework is stopped after a certain period, a rebound effect is expected in this case too, due to the increase of social contacts.
- The role of children in COVID-19 transmission is still unclear. Here we used a low susceptibility and moderate infectivity relative to adults, based on outbreak data in China. While the estimates for susceptibility and infectivity will be further refined based on confirmed data for France, our results show that scenarios with largely different susceptibility/infectivity of children vs. adults show similar behavior in terms of timing and effectiveness of school closure and telework in the French regions under study. This is due to the larger contribution of the population in the adult age class, not affected by this assumption, to the incidence curve. Larger attack rates are however predicted, as expected. Populations characterized by younger age profiles will be more sensitive to these parameters, which still remain unknown.
- Isolation of cases is extremely important in the mitigation of the epidemic. The reduction of contacts in 55%of adults when ill is shown to lower the final attack rate of about 13%(Île-de-France). Self-isolation should be strongly promoted for all symptomatic individuals following symptoms onset, even if mild.
- Generalizing these results to other countries would require parameterizing the model with the country-specific age profile and social contact matrices.

LIMITATIONS

- As a proxy for mixing patterns occurring during school closure, we use data from contacts established in France in a holiday period. No data currently exist that account for the change of behavior of children and adults during an emergency school closure as during this health crisis. Mixing patterns may be different compared to a holiday that is planned well in advance in the calendar. Compensatory behaviors, such as increasing the contacts between children and grandparents (though strictly not recommended), may result from the sudden reorganization of daily routines. Conversely, a more optimistic scenario may consider that children establish contacts exclusively in their household once schools are closed. However, this is likely to happen if stricter measures imposing staying at home except for essential needs are implemented, similarly to mitigation measures already adopted in Belgium and Italy. Data collection efforts are needed to better quantify these patterns over time[34].
- We assumed that 55% of adults would change their behavior in their symptomatic phase reducing their contacts, based on data from the Italian COVID-19 outbreak and contact reduction reported during 2009 H1N1 pandemic influenza[27]. The parameterization of the model will be refined to better capture change of behavior of French population while ill with COVID-19. This can be done from data obtained through the online participatory surveillance system GrippeNet.fr[35,36].
- Multiple age classes are needed to accurately evaluate the impact on the healthcare system, and estimate the resource needs (personnel, equipment, beds) over time.
- We assumed two values of case underreporting, in absence of estimates for the epidemic in France. With clearer epidemic trends from sentinel surveillance[19] the model will be used to fit the observed incidence profiles in the various regions and provide more accurate temporal predictions.

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