Expected impact of reopening schools after lockdown on COVID-19 epidemic in Île-de-France

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ABSTRACT

As several countries around the world are planning exit strategies to progressively lift the rigid social restrictions implemented with lockdown, different options are being chosen regarding the closure or reopening of schools. We evaluate the expected impact of reopening schools in Île-de-France region after the withdrawal of lockdown currently scheduled for May 11, 2020. We explore several scenarios of partial, progressive, or full school reopening, coupled with moderate social distancing interventions and large-scale tracing, testing, and isolation. Accounting for current uncertainty on the role of children in COVID-19 epidemic, we test different hypotheses on children's transmissibility distinguishing between younger children (pre-school and primary school age) and adolescents (middle and high school age). Reopening schools after lifting lockdown will likely lead to an increase in the number of COVID-19 cases in the following 2 months, even with lower transmissibility of children, yet protocols exist that would allow maintaining the epidemic under control without saturating the healthcare system. With pre-schools and primary schools in session starting May 11, ICU occupation would reach at most 72% [55,83]% (95% probability ranges) of a 1,500-bed capacity (here foreseen as the routine capacity restored in the region post-first wave) if no other school level reopens before summer or if middle and high schools reopen one month later through a progressive protocol (increasing attendance week by week). Full attendance of adolescents at school starting in June would overwhelm the ICU system (138% [118,159]% occupation). Reopening all schools on May 11 would likely lead to a second wave similar to the one recently experienced, except if maximum attendance is limited to 50% for both younger children and adolescents. Based on the estimated situation on May 11, no substantial difference in the epidemic risk is predicted between progressive and prompt reopening of pre-schools and primary schools, thus allowing full attendance of younger children mostly in need of resuming learning and development. Reopening would require however large-scale trace and testing to promptly isolate cases, in addition to moderate social distancing interventions. Full attendance in middle and high schools is instead not recommended. Findings are consistent across different assumptions on the relative transmissibility of younger children and for small increase of the reproductive number possibly due to decreasing compliance to lockdown.

INTRODUCTION

Countries are slowly unveiling strategies to lift their lockdown restrictions as rates of COVID-19 infection continue to fall. They aim to strike a delicate balance between reviving the economy and relieving social pressure while averting a potentially devastating second wave of infections. Plans for lifting lockdown are quite heterogeneous in Europe[1], and a large debate sparked regarding the closure or reopening of schools. Italy and Spain have chosen to adopt restrictive and conservative solutions, keeping schools closed until September to preserve children's health[2,3]. Denmark and Norway already reopened their primary schools[4,5]. Austria plans to allow students to go back to school on May 18 with alternating classes, i.e. splitting students in two groups, each attending lessons during half of the week. Greece will restart classes with high schools first, on May 11, followed possibly by pre-schools and primary schools on June 1, if epidemic conditions remain favorable.

On April 28, French authorities presented the exit strategies, with a progressive plan to reopen schools[6]. Pre-schools and primary schools are expected to reopen on May 11, considering that classes will be limited to groups of 15 and attendance will be on a voluntary basis. Middle schools may follow one week later, but only in those departments weakly affected by the epidemic. Middle school students will be asked to wear masks, differently from younger children[7]. Reopening of high schools will be decided in late May, depending on the epidemic evolution. Universities will remain closed till next academic year.

Assessing the risk that school reopening may have on the transmission of the epidemic faces a key challenge, as the role of children in COVID-19 spread is not yet well understood. Current evidence from household studies, contact tracing investigations, and modeling works suggest that children are as likely to be infected by COVID-19 as adults, but more likely to become either asymptomatic or paucisymptomatic[8–11]. This may explain the very small percentage (<5%) of children in COVID-19 confirmed cases worldwide[12]. Their role in acting as source of infection remains unclear.

Epidemic data so far does not show the typical signature of widespread school outbreaks reported in past influenza pandemics, and responsible for driving transmission in the community[13–17]. However, such transmission could have gone unobserved because of (i) asymptomatic infections in children, (ii) testing restricted to symptomatic cases during the early phase of the outbreak, (iii) early school closure as reactive measure, or schools not in session because of holidays (e.g. in South Korea in January). A retrospective analysis of the Oise cluster in northern France showed evidence for large asymptomatic viral circulation in a high school, whereas case investigation and contact tracing had identified only two symptomatic cases (testing was not performed in absence of symptoms)[18]. Also, the closure of school for winter holidays in mid-February led to a substantial drop in the number of symptomatic cases, confirming the central role of the high school in the observed cluster.

Adolescents, however, may have a different role in driving the epidemic spread compared to younger children. Massive testing in Iceland and in the municipality of Vo', Italy, the initial epicenter of the Italian outbreak, showed that children under 10 years of age had a lower incidence of COVID-19 than adolescents and adults[19,20].

Multiple evidence therefore suggests that younger children have a weaker role in COVID-19 transmission dynamics than adolescents. Accounting for current uncertainties, here we focus on the role of contacts at schools and the impact that different protocols for school reopening may have on the control of the epidemic in the upcoming months. In a previous work[21] we proposed different exit strategies to relax the stringent constraints of lockdown on social life and economy while curtailing the burden on the health-care system. All explored measures however assumed that schools remained closed at all time. Here we simulate scenarios of partial, progressive or full reopening of schools, with differential opening of pre-school and primary schools vs. middle and high schools, following the plan illustrated by the French Government[6]. School reopening according to different protocols is compared with the scenario where all schools remain closed after lockdown ends. School reopening or closure is coupled with moderate social distancing interventions[21] and large-scale case tracing, testing, and isolation. The study is applied to Île-de-France, the most affected region by the COVID-19 epidemic in France, and is updated to the most recent data on the epidemic trajectory in the region.

METHODS

We use a stochastic discrete age-structured epidemic model based on demographic and age profile data[22] of the region of Île-de-France. Four age classes are considered: [0-11), [11-19), [19-65), and 65+ years old. The first class includes ages of students in pre-school and primary school, and the second class corresponds to students in middle and high school. We use social contact matrices measured in France in 2012[23] to account for the mixing, in the no interventions scenario, between individuals in these age groups, depending on the type of activity and place where the contacts occur (household, school, workplace, transport, leisure, other). Transmission dynamics follows a compartmental scheme specific for COVID-19 (**Figure 1**), where individuals are divided into susceptible, exposed, infectious, hospitalized, in ICU, recovered, and deceased. The infectious phase is divided into two steps: a prodromic phase (I_p) and a phase where individuals may remain either asymptomatic (I_a) or develop symptoms. In the latter case, we distinguished between different degrees of severity of symptoms, ranging from paucisymptomatic (I_{ps}), to infectious individuals with mild (I_{ms}) or severe (I_{ss}) symptoms. Asymptomatic and paucisymptomatic individuals have a reduced transmissibility r_β = 0.55, as estimated in Ref.[24]. Here we show results for a probability of being asymptomatic p_a =20%[25]; a sensitivity analysis on this value was performed in a previous work[21]. Time spent in each compartment is assumed to follow an exponential distribution, except duration in ICU which is modelled through a gamma distribution, as it best captured the data. Parameters, values, and sources used to define the compartmental model are listed in **Table S1** of the Appendix.

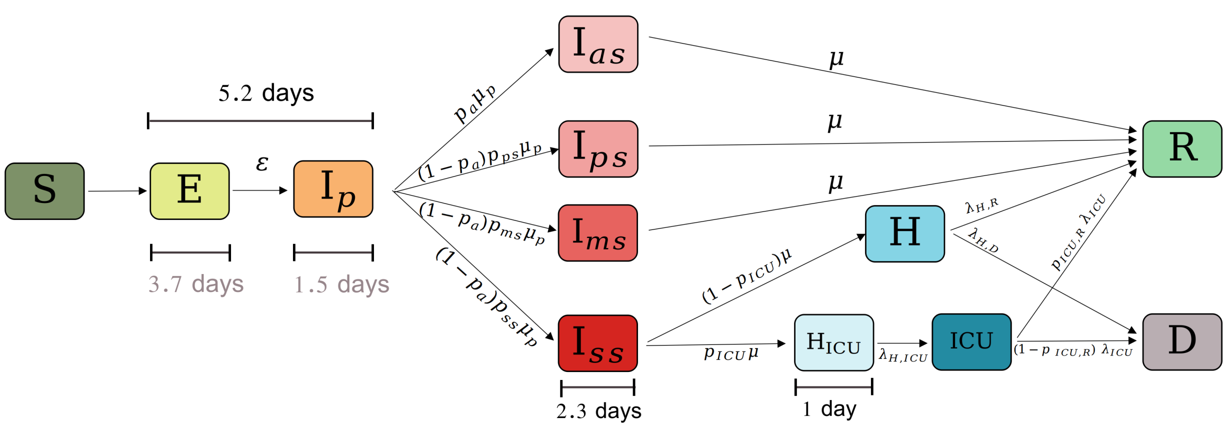

Figure 1. Compartmental model. S=Susceptible, E=Exposed, I_p= Infectious in the prodromic phase (the length of time including E and I_p stages is the incubation period), I_a=Asymptomatic Infectious, I_{ps}=Paucysymptomatic Infectious, I_{ms}=Symptomatic Infectious with mild symptoms, I_{ss}=Symptomatic Infectious with severe symptoms, H_{ICU}= severe case who

will enter in ICU, ICU=severe case admitted to ICU, H=severe case admitted to the hospital but not in intensive care, R=Recovered, D=Deceased.

Intervention measures are modeled through modifications of the contact matrices, accounting for a reduction of the number of contacts engaged in specific settings. For example, the lockdown matrix is constructed assuming 70% of workers not going to work (because of telework, closure of activity, caring for children not going to school, and other cases), school closure, 90% reduction of contacts established by seniors, and closure of non-essential activities. In Ref.[21] we explored progressive exits from lockdown, with social distancing interventions of different degrees of intensity (strict, moderate, mild) coupled or not with case finding, testing and isolation. Following announcements by authorities, here we consider *Exit 1*[21], a combination of moderate interventions with efficient tracing, testing and isolation of cases (**Table 1**). Moderate interventions consider that 50% of adults do not go to work, 50% of non-essential activities remain closed, contacts of seniors are reduced by 75%, and contacts on transport are reduced according to presence of workers and reopening of activities. These social distancing interventions are combined with isolation of 50% of cases through a 90% reduction of their contacts, simulating the result of rapid and efficient tracing and testing of cases[21]. A sensitivity on the rate of case isolation is also performed.

The model was calibrated to hospital admission data before lockdown, and to ICU admission data during the lockdown phase considering data in the interval April 8-28, 2020, to avoid fluctuations observed after lockdown entered into effect.

Table 1. Exit strategies following the lifting of the lockdown (more details provided in Ref.[21]).

	School closure / reopening	**Telework (=% of individuals not going to work)**	**Senior isolation**	**Closure non-essential activities**	**Case isolation**
Lockdown	School closure	70%[26]	Yes, with 90% contact reduction	Yes, 100% closure	No
Set of moderate interventions + case isolation	School closure or Reopening through scenarios of Fig. 1	50% [27]	Yes, with 75% contact reduction	Yes, 50% closure	Yes, for 50% of cases (25% tested for sensitivity)

Role of children. We consider the two classes of children to be equally susceptible as adults, and to become either asymptomatic or paucisymptomatic only following Refs. [9,10,21,24]. Viral load is similar across age classes[28] and across asymptomatic and symptomatic cases[20,29,30], however the risk of transmission was shown to vary with the severity of symptoms[31]. Given the role of asymptomatic infection in high school students observed in the Oise cluster[18], we assume that adolescents have the same reduction in transmissibility as adults in absence of symptoms[18–20], $r_\beta = 0.55$[24]. We account for the weaker role of younger children in acting as source of infection by exploring 4 different values for their reduction in transmissibility compared to adolescents and adults: $r_\beta^{[0-11)} = 0.1, 0.25, 0.33, 0.55$.

Scenarios for reopening of schools. We simulate the reopening of schools on May 11 through three sets of four different scenarios, including progressive, partial, and full reopening, differentiated for type of schools (pre-school, primary, and middle, high school). Partial reopening means that at most 50% of students return to school, envisioning for example a rotation of students every half of the week or every week, or considering 50% attending in the morning and 50% in the afternoon. Progressive reopening is tested starting with an attendance of 25% in the first week that gradually increases over the following weeks, up to 50% (partial attendance) or 100% (full attendance). Full reopening starting on May 11 is also considered.

The first set of scenarios foresees the reopening of pre-schools and primary schools only, on May 11, whereas middle and high schools would remain closed till next school calendar (**Figure 2**):

- *Progressive (100%)* : progressive reopening up to 100% attendance. We assume that 25% of students go back to school on the 1st week after lockdown is lifted, 50% on the 2nd, 75% on the 3rd, and 100% from the 4th week till summer holidays.
- *Progressive (50%)* : progressive reopening up to 50% attendance. We assume that 25% of students go back to school on the 1st week after lockdown is lifted, and 50% from the 2nd week till summer holidays.
- *Prompt (50%)* : partial reopening with 50% attendance from May 11.
- *Prompt (100%)* : full reopening with 100% attendance from May 11.

Contacts at schools are proportional to school attendance in the various scenarios.

Figure 2. Protocols of school reopening. The first set of scenarios considers the reopening of pre-schools and primary schools only, on May 11, through *Progressive (100%)*, *Progressive (50%)*, *Prompt (50%)*, and *Prompt (100%)* protocols. Colors indicate student attendance (from lighter to darker, 25% to 100% at 25% incremental steps). The second set of scenarios considers the reopening of pre-schools and primary schools on May 11, only through *Progressive (100%)*, followed by the reopening of middle and high schools on June 8 through all 4 possible protocols. A sensitivity scenario assuming *Prompt (100%)* for pre-schools and primary schools is provided in Appendix. The third set of scenarios considers the reopening of all schools on May 11, with all schools following the same protocol.

The second set of scenarios considers the scenario *Progressive (100%)* for pre-school and primary schools starting May 11, coupled with the reopening of middle and high schools 4 weeks after (June 8) through progressive or prompt protocols at full or partial attendance (i.e. as before, but for adolescents and starting on June 8). This set of scenarios is closer to the plan recently announced by the French Government, accounting that Île-de-France has been highly affected, so school opening for secondary school may occur later compared to less affected regions. For sensitivity, we also consider the scenario *Prompt (100%)* for pre-school and primary school starting May 11, followed by the 4 scenarios for middle and high schools starting June 8 (**Figure S3**).

Finally, the third set of scenarios assume that all school levels, from pre-school to high school, would reopen after lifting the lockdown on May 11, through progressive or prompt protocols at full or partial attendance.

All scenarios are compared to the situation where schools remain closed.

Summer vacations last from July 5 to August 31, 2020. The model cannot be easily parameterized during summer holidays because of lack of data and lack of information on recommendations for those months. For the simulations with reopening of schools, we used the number of contacts established by children during spring holidays, estimated by the social contact survey in France[23]. Holidays for adults were not modeled. We do not evaluate the epidemic trajectory during summer holidays (except for ICU occupancy due to the intrinsic delay in admission and occupation, see below), as the parameterization of the model has still too many uncertainties.

Evaluation. Each scenario of school reopening is evaluated in terms of: number of clinical cases at the start of summer holidays (July 5, 2020) compared to the school closure scenario; ICU beds demand on August 1, to account for cases generated before summer holidays and the average delay due to disease progression. Current capacity of ICU beds in the region was largely strengthened during the first wave of the epidemic (approximately from 1,200 to 2,800 beds)[32]. To evaluate the school reopening scenarios, we foresee an ICU capacity restored at 1,500 beds in the months following the emergency, i.e. considering a 25% increase compared to standard pre-COVID-19 size.

For each scenario, we perform 250 stochastic runs; median curves are displayed together with the associated 95% probability ranges.

Sensitivity analysis. We investigate social distancing measures based on moderate interventions coupled with a smaller rate of testing and isolation of cases (25%). We additionally perform the analysis also assuming that the reproductive number during lockdown is 10% lower or higher than the one estimated on current data. We evaluate the reopening of middle and high school starting June 8 (second set of scenarios), considering a full attendance of younger children starting May 11.

RESULTS

Epidemic situation projected for May 11, 2020. Calibrating the model in the lockdown phase to ICU admission data up to April 28, 2020, we estimate a drop of the reproductive number from R_0 =3.0 [2.8, 3.2] (95% confidence interval) prior to lockdown[21] to R_{LD} =0.53 [0.49, 0.58] during lockdown, in agreement with recent estimates[33,34]. If current lockdown effects remain, model projections indicate that by May 11 the region may experience 350 [268, 421] new clinical cases per day (corresponding to 710 [555, 869] new infections), 18 [10, 28] new admissions in ICUs, with an ICU system occupied at 42% [33, 52]% of currently strengthened capacity (**Figure 3**). Estimated fluctuations refer to 95% probability ranges from simulations parameterized with R_{LD} =0.53.

Our projections for ICU demand slightly overestimate the data, as they do not account for the transfer of patients in intensive care to less affected regions.

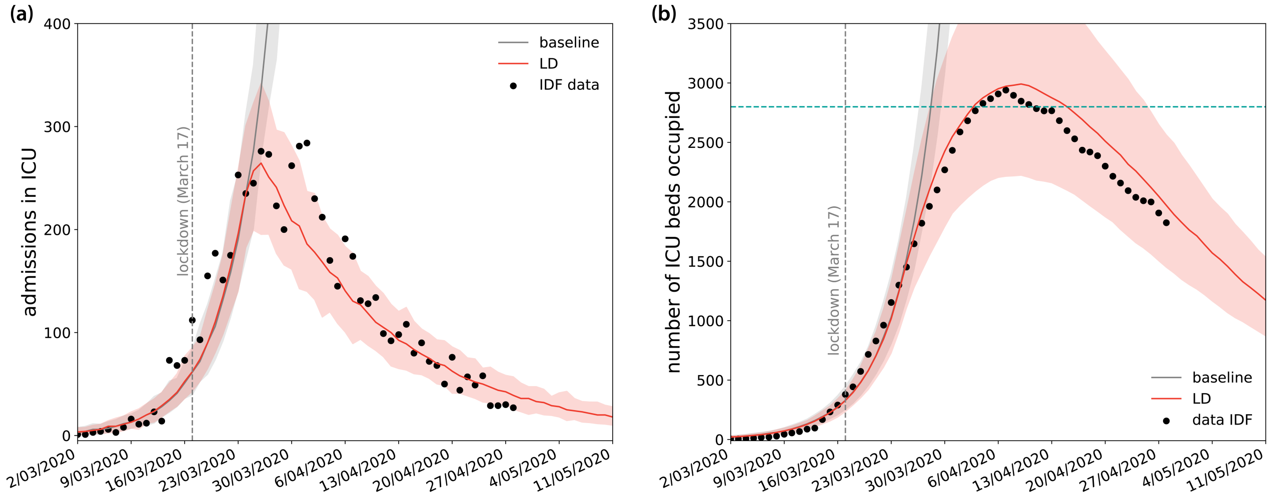

Figure 3. Simulated epidemic trajectories till May 11. (a) Simulated daily incidence of admissions in ICU over time. (b) Simulated number of ICU beds occupied over time. Vertical dashed line refers to the start of the lockdown; shaded areas correspond to 95% probability ranges; horizontal line refers to strengthened ICU capacity in the region to face the first COVID-19 wave[32].

These projections are obtained assuming that the reproductive number does not change throughout the lockdown phase and are based on data up to April 28. If the spreading potential was 10% lower or higher than the estimated R_{LD}, the projected number of new clinical cases on May 11 would be 182 [135, 228] or 624 [469, 796], respectively, corresponding to an ICU demand of 32% [25, 40]%, or 55% [45, 71]% of currently strengthened capacity.

Reopening of schools. If only pre-schools and primary schools are reopened starting May 11 till the end of the school calendar, the projected number of new clinical cases at the start of summer holidays (July 5) is 2 to 3.2 times the number expected with schools closed, depending on the reopening protocol and the transmissibility of younger children (**Figure 4a,d** and **Figure 6a**). Though increasing, the epidemic remains under control, with an expected maximum occupation of the ICU system on August 1 equal to 65%[54,76]% of the foreseen 1,500-bed capacity (**Fig. 5a**, **7a**). No difference between protocols is observed when transmissibility of younger children is less than or equal to half the transmissibility of adolescents ($r_\beta^{[0-11)} = 0.1, 0.25$; **Fig. 4d, 6a,** and **Figure S1** of the Appendix). If $r_\beta^{[0-11)}$ is larger, maximum attendance mainly determines the increase of cases, whereas progressive and prompt protocols do not show substantial differences.

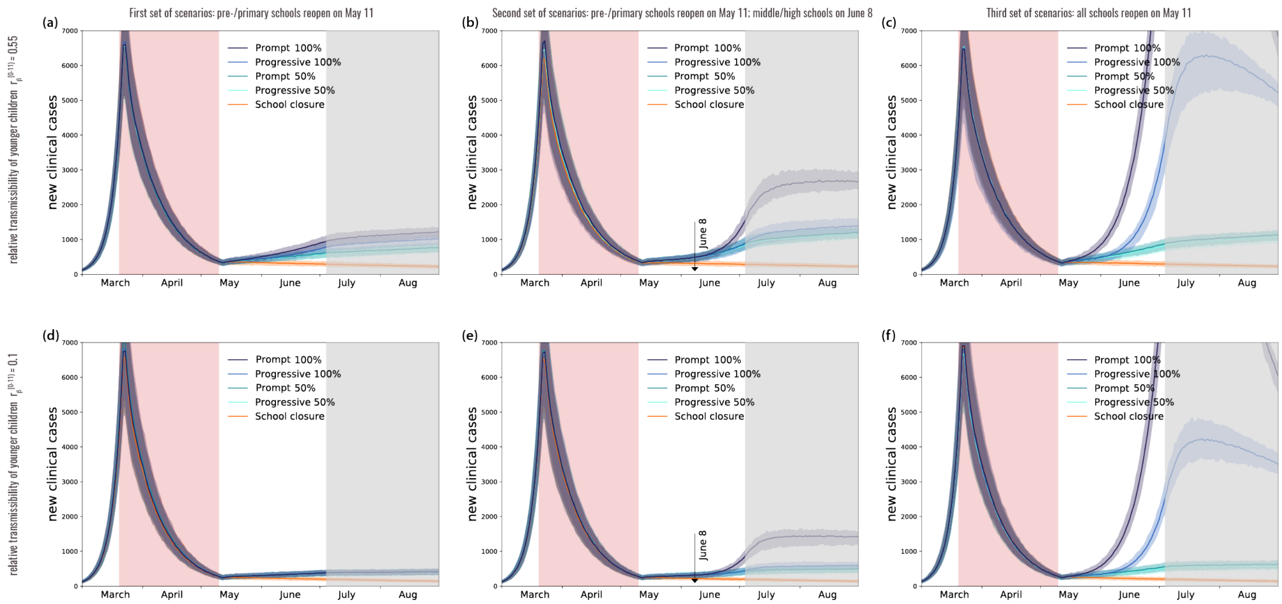

Figure 4. Simulated epidemic activity in scenarios with reopening of schools. (a-c) Simulated daily number of new clinical cases assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.55, i.e. younger children are as infectious as adolescents. (d-f) As panels (a-c) assuming $r_\beta^{[0-11)}$ =0.1. Results for other values of $r_\beta^{[0-11)}$ are reported in the Appendix. The red area indicates the lockdown phase; the grey area indicates summer holiday. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

Additionally reopening middle and high schools starting June 8 would lead to an epidemic situation similar to the scenario with largest epidemic activity predicted for reopening lower educational levels only (*Progressive (100%, 50%)* and *Prompt (50%)* of **Fig. 4b, 6b** compared to *Prompt (100%)* of **Fig. 4a, 6a**), if attendance is limited to 50%. These scenarios would lead to a maximum ICU demand equal to 72%[55,83]% of foreseen capacity. With full attendance in middle and high schools on June 8 (*Prompt (100%)* of **Fig. 4b, 6b**), the new number of clinical cases per day would be 4.5 to 5.5 times higher relatively to the school closure scenario at the start of the summer (median values; **Fig. 6b**), leading to 77% [62,87]% to 138% [118,159]% ICU occupation by mid-summer (**Fig. 7b**), depending on younger children transmissibility. Results do not change if pre-schools and primary schools fully reopen on May 11 (**Figure S3-S5**).

If all schools reopen on May 11 with full attendance, a larger second wave is predicted in the upcoming months, even under a progressive reopening (*Prompt (100%), Progressive (100%)* of **Fig. 4c, 6c**). To avoid this situation and to keep the epidemic under control, limiting attendance to 50% per day would be key (maximum demand on ICU system expected to be between 35% [27,42]% and 61% [50,69]% of foreseen ICU capacity; **Fig. 5c,f** and **Fig. 7c**).

Among the scenarios allowing the epidemic to be controlled, the model predicts a maximum of 1,000 cases per day in the region who are promptly tested and put in isolation.

Results are robust against a 10% increase of the reproductive number during lockdown (**Figures S6,** with worst case scenarios reaching saturation). Reopening schools maintaining the epidemic under control would however require fast and massive tracing and testing of cases to allow their isolation. All scenarios obtained with 25% case isolation would overwhelm the ICU system by mid-summer (**Figures S7-S9**).

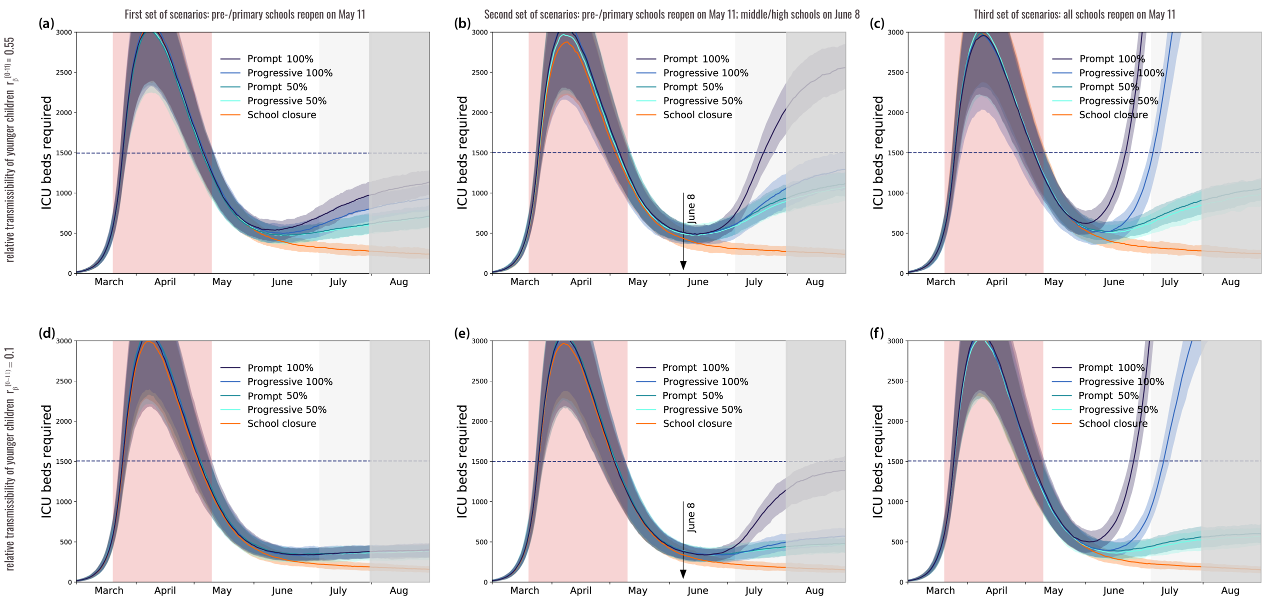

Figure 5. Simulated ICU occupancy in scenarios with reopening of schools. (a-c) Simulated demand of ICU beds assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.55, i.e. younger children are as infectious as adolescents. (d-f) As panels (a-c) assuming $r_\beta^{[0-11)}$ =0.1. Results for other values of $r_\beta^{[0-11)}$ are reported in the Appendix. The red area indicates the lockdown phase; the grey area indicates summer holiday (lighter grey in the month of July to show the delayed effect of the epidemic on ICU demand). Horizontal line refers to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

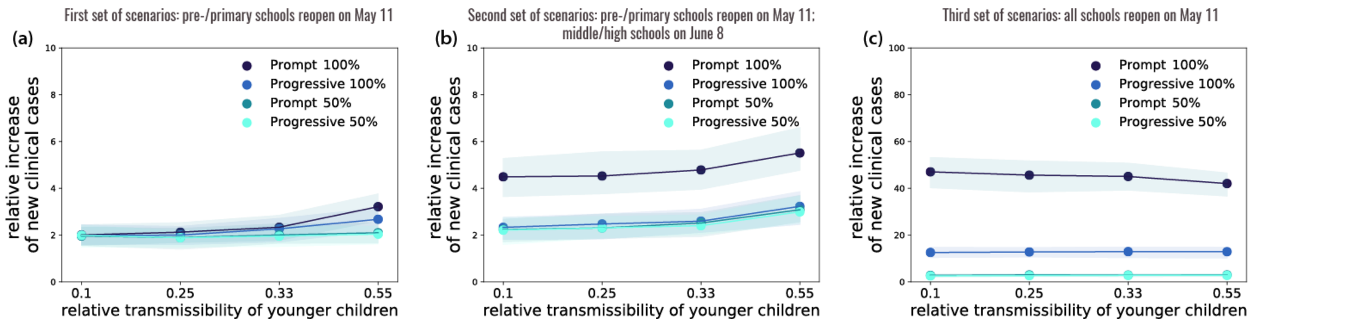

Figure 6. Impact of reopening schools on epidemic activity. (a-c) Projected increase in the daily number of new cases relative to the school closure scenario on July 5 (start of summer holidays) as a function of the relative transmissibility of younger children, for different reopening protocols. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

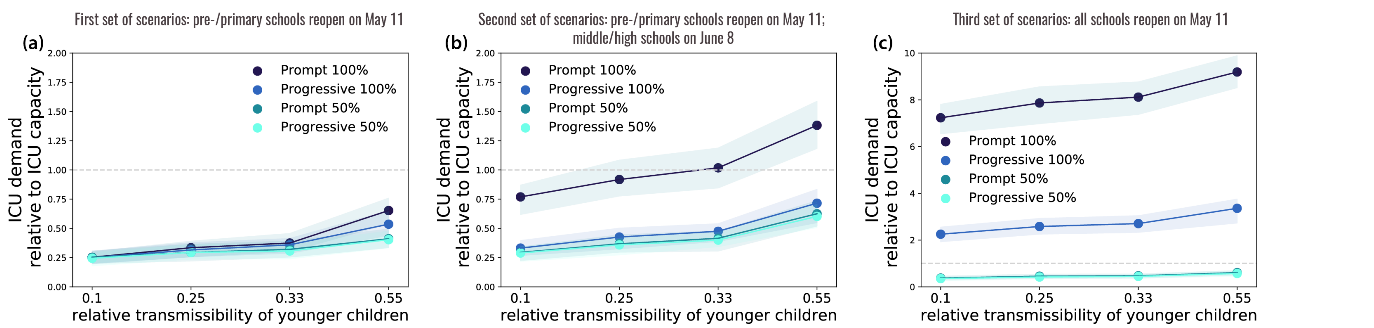

Figure 7. Impact of reopening schools on ICU occupancy. (a-c) Projected ICU demand on August 1 relative to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency, as a function of the relative transmissibility of younger children, for different reopening protocols. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

DISCUSSION

Reopening schools after lifting the lockdown will likely lead to an increase in the number of COVID-19 cases in the following 2 months, even with lower transmissibility in children, yet protocols exist that would allow maintaining the epidemic under control without saturating the healthcare system. With pre-schools and primary schools in session starting May 11, ICU occupation would remain below the foreseen 1,500-bed capacity (at most 72% [55,83]%) , as long as middle and high schools reopen one month later and limit students' attendance. Healthcare demand would exceed foreseen capacity (138% [118,159]%) if middle and high schools fully reopen in June accepting all students. These findings are consistent across different assumptions on the relative transmissibility of younger children, however they require intensive large-scale tracing, testing, and isolation of cases, coupled with moderate social distancing interventions.

The impact of school reopening on ICU occupancy will only be visible after a certain delay, due to the natural progression of the disease and also the long time period during which a patient requires intensive care. COVID-19 activity indicators estimated by the sentinel surveillance system[35] need to be closely monitored to anticipate surge of patients. Additionally, massive testing targeting case contacts to break the chains of transmission through isolation will, at the same time, provide a reliable indicator to react in a more rapid and agile way to the evolving epidemic situation and revise social distancing recommendations.

Easing exit strategies through progressive reopening of schools may help the preparation of schools to welcome younger children in the class. No substantial difference in the epidemic risk is predicted between progressive and prompt reopening of pre-schools and primary schools. In light of the remaining 8 weeks in the school calendar, full attendance of younger children in pre-schools and primary schools is thus possible. This would allow resuming learning and development for all students in the age classes mostly in need[36]. Full attendance in middle and high schools is instead not recommended. Our findings are based on current evidence suggesting that higher school levels may become important settings for transmission[18], being then responsible for spreading the epidemic in the community. Virological evidence indicates that no significant difference in viral load is observed across age[28], or between symptomatic and asymptomatic infections[20,29,30]. Transmission, however, is mediated by symptoms and their severity[31], possibly explaining why younger children have a limited role as source of transmission[37,38]. Additional epidemiological and virological investigations are urgently needed to better characterize the role of children in the transmission dynamics of the disease, across age classes (e.g. also distinguishing between middle school and high school students), both at schools and in the community.

Our results are based on projections estimated on data as of April 28, 2020 and assume that the reproductive number does not change throughout the lockdown phase. A 10% increase in the reproductive number than estimated from data, to account for uncertainty in the estimation or for reduced compliance to lockdown restrictions in the last weeks before May 11, would not affect our main results.

In the scenario analyses, occupation of ICU system was not evaluated on the basis of current capacity[32]. Such capacity (approximately 2,800 beds in Île-de-France) was largely strengthened as an emergency response to cope with the large influx of COVID-19 patients requiring critical care during the first wave. It required not only additional material (beds, respirators, rooms, etc.) but also personnel who was transferred from other medical specialties to support the increase in response. Exiting the current emergency, we envision that ICU capacity will be restored to lower levels for the upcoming months, as the system has been stretched to limits that are not sustainable in the long term. We foresee a capacity of 1,500 beds, considering a 25% increase compared to pre-COVID-19 epidemic size to re-establish almost routine conditions while accounting for the need to continue facing a pandemic situation for the next several months. The aim is to avoid a second epidemic wave as large as the first one. If a second emergency would occur, the system would need to be strengthened again to higher limits.

We considered moderate social distancing interventions, as previously done[21], as they envision that a certain percentage of workers would resume their professional activity, including the partial reopening of commerce. This scenario is in line with current plans of authorities[6] and it is predicted to maintain the epidemic under control if massive targeted testing is also implemented. According to model projections, a maximum of about 1,000 infected individuals per day will need to be isolated in Île-de-France at the largest epidemic activity (end of school calendar) in the scenarios allowing control of the epidemic. Targeting a range of 5% to 10% positivity rate of performed tests[39], 10,000 to 20,000 tests per day would thus be required in the region. These estimates are within the ballpark of expected regional capacity, considering the objective of 700,000 tests by week at national level[40] and assuming a population-based distribution by region (i.e. about 18,000 tests per day in Île-de-France). A massive effort in human resources is required to conduct epidemiological investigations to rapidly and efficiently identify suspect cases. A less efficient tracing, testing and isolation of cases would not be able to avoid a second wave. Epidemic scenarios presented here will need to be refined and recalibrated once estimates on telework, increase of mobility, density in public transports etc. will become available after lockdown is lifted. This will also allow to better estimate interventions and testing capacity needs.

We did not consider the generalized use of masks, required in public transports and recommended in open places once lockdown ends[6], as estimates are not yet available on their effectiveness as preventive measures. If effective, their widespread use may help decrease the risk of transmission in the community. As more epidemiological evidence accrues, this effect can be taken into account and help further alleviate control measures. We modeled epidemic trajectories through summer to estimate the delayed impact that 8 weeks of schools in session in May and June may have on the hospital system in the month of July. However, we cannot accurately parameterize the model during summer, because of lack of contact data (we used Spring holiday contact data as a proxy instead) and of information about control measures and protocols for holidays that will be enforced during summer months (we considered moderate social distancing measures still in effect, with no holidays). Also, we did not consider seasonal behavior in viral transmission[41,42], as this is still under investigation. Due to these large uncertainties, the trajectory of the number of cases during summer cannot be considered accurate and should be interpreted with caution. We did not study reactive school closure as a means to slow down propagation[43,44], as our study was focused on the conditions allowing reopening for the last two months of the school calendar. Reactive school closure will be studied to prepare for next school calendar. We focused on Île-de-France region, following our previous work[21], and did not consider spatially targeted reopening within the region[45].

Given the heterogeneous situation in Europe regarding exit strategies, and more specifically the opening or closure of schools[1], surveillance of changes in epidemic activity also in other countries will become critical in the next few weeks to learn from these experiences and adapt the exit strategy where needed.

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APPENDIX

Compartmental model

Table S1. Parameters, values, and sources used to define the compartmental model

Variable	Description	Value	Source
θ^{-1}	Incubation period	5.2d	1
μ_p^{-1}	Duration of prodromal phase	1.5d, computed as the fraction of pre-symptomatic transmission events out of pre-symptomatic plus symptomatic transmission events	2
ϵ^{-1}	Latency period	$\theta^{-1} - \mu_p^{-1}$	-
p_a	Probability of being asymptomatic	0.2	3
p_{ps}	If symptomatic, probability of being paucisymptomatic	1 for younger children, adolescents 0.2 for adults, seniors	4
p_{ms}	If symptomatic, probability of developing mild symptoms	0 for younger children, adolescents 0.7 for adults 0.6 for seniors	4
p_{ss}	If symptomatic, probability of developing severe symptoms	0 for younger children, adolescents 0.1 for adults 0.2 for seniors	4–6
s	Serial interval	7.5d	7
μ^{-1}	Infectious period for I_a, I_{ps}, I_{ms} , I_{ss}	$s - \theta^{-1}$	-
r_β	Relative infectiousness of I_p, I_a, I_{ps}	0.1, 0.25, 0.33, 0.55 for younger children 0.55 for adolescents, adults, seniors	8
p_{ICU}	If severe symptoms, probability of going to ICU	0.36 for adults 0.2 for seniors	9
$\lambda_{H,R}$	If hospitalized, daily rate entering in R	0.072 for adults 0.022 for seniors	9
$\lambda_{H,D}$	If hospitalized, daily rate entering in D	0.0042 for adults 0.014 for seniors	9
$\lambda_{H,ICU}^{-1}$	Waiting time in hospital before entering ICU	1d for adults, seniors	9
$p_{ICU,R}$	Probability of recovery from ICU	0.69 for adults 0.41 for seniors	9
λ_{ICU}^{-1}	Time spent in ICU, modeled as a gamma distribution with shape parameter 2 and rate parameter $2\lambda_{\mathrm{ICU}}$	22d for adults 20d for seniors	10

Additional results corresponding to values of younger children relative transmissibility not shown in main paper

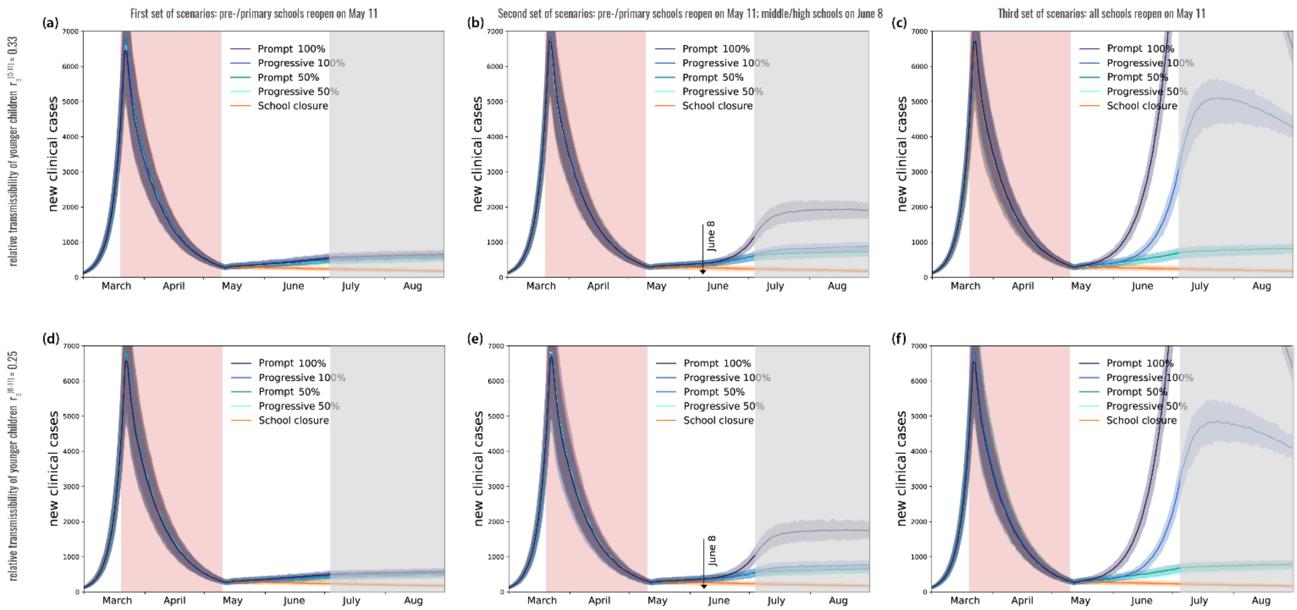

Figure S1. Simulated epidemic activity in scenarios with reopening of schools. (a-c) Simulated daily number of new clinical cases assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.33. (d-f) As panels (a-c) assuming $r_\beta^{[0-11)}$ =0.25. The red area indicates the lockdown phase; the grey area indicates summer holiday. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

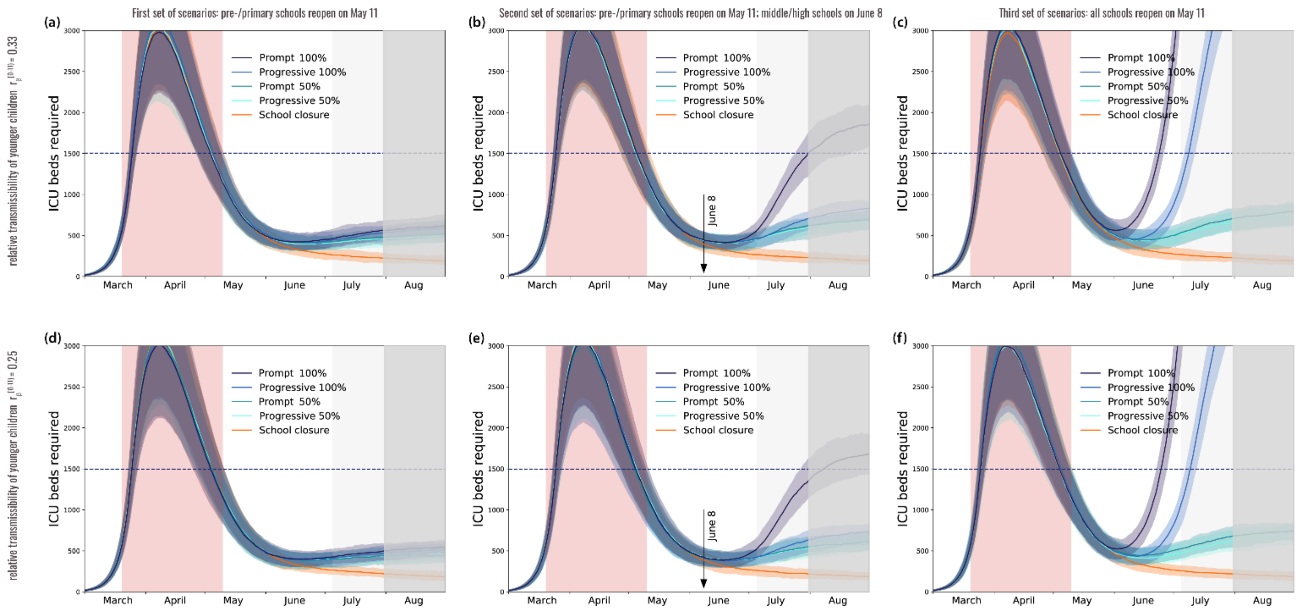

Figure S2. Simulated ICU occupancy in scenarios with reopening of schools. (a-c) Simulated demand of ICU beds assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.33. (d-f) As panels (a-c) assuming $r_\beta^{[0-11)}$ =0.25. The red area indicates the lockdown phase; the grey area indicates summer holiday (lighter grey in the month of July to show the delayed effect of the epidemic on ICU demand). Horizontal line refers to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

Results obtained with an additional set of scenarios

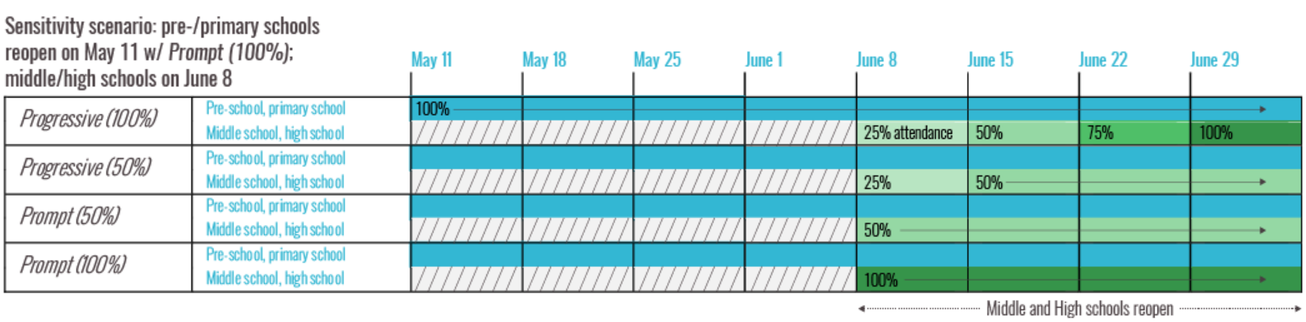

Figure S3. Sensitivity scenarios of school reopening. This set of scenarios considers the reopening of pre-schools and primary schools on May 11 through *Prompt (100%)* , followed by the reopening of middle and high schools on June 8 through all 4 possible protocols. This is a variation of the second set of scenarios (Fig. 1). Colors indicate student attendance (from lighter to darker, 25% to 100% at 25% incremental steps).

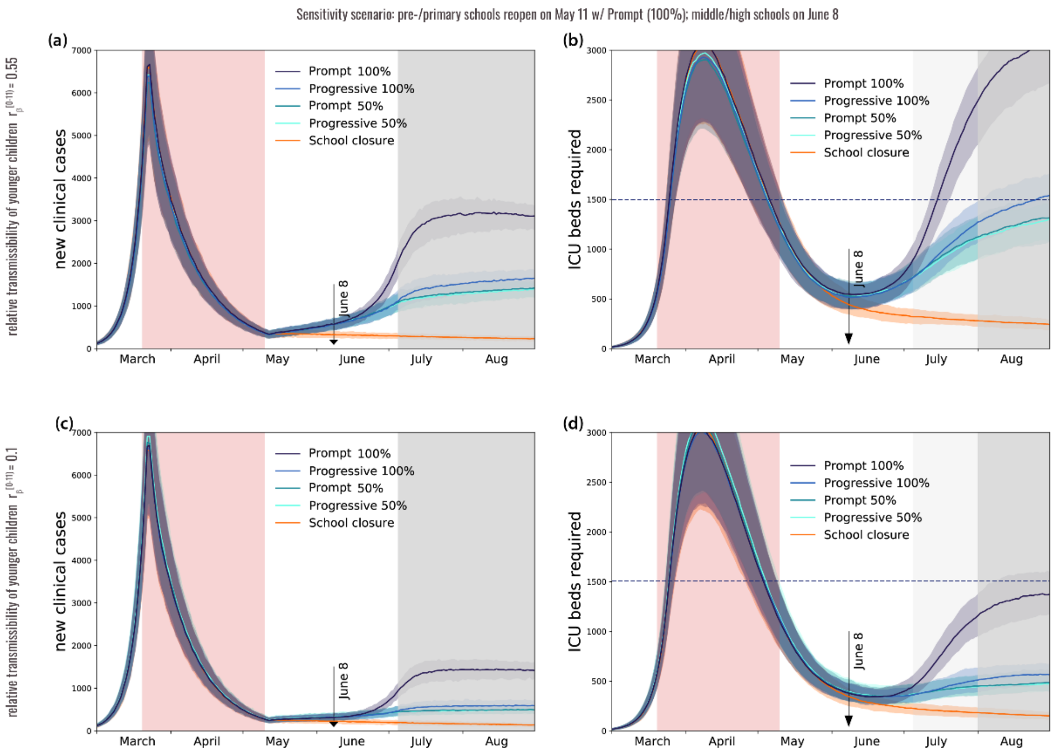

Figure S4. Simulated epidemic activity and ICU occupancy in the sensitivity scenarios of school reopening. (a-b) Simulated daily number of new clinical cases (panel a) and simulated demand of ICU beds (panel b) assuming that all pre-schools and primary schools are promptly reopened on May 11, followed by the reopening of middle and high schools on June 8 through four different protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*). Results are obtained for a relative transmissibility of younger children $r_{\beta}^{[0-11)}$ =0.55. (c-d) As (a-b) with $r_{\beta}^{[0-11)}$ =0.1. The red area indicates the lockdown phase; the grey area indicates summer holiday. Horizontal line in (b-d) refers to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency. Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

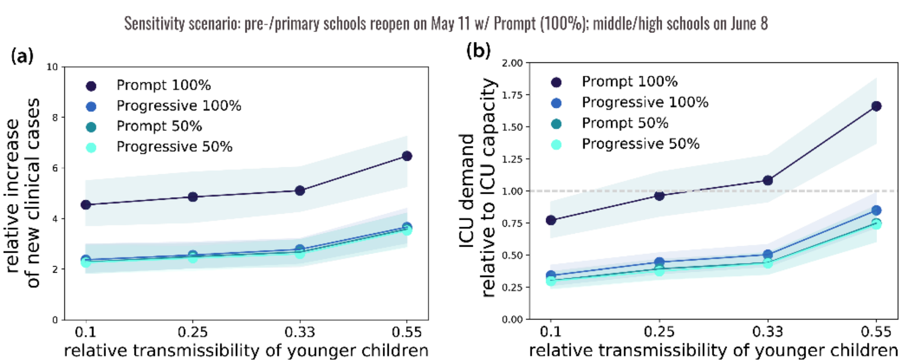

Figure S5. Simulated impact of reopening schools in in the sensitivity scenarios of school reopening. (a) Projected increase in the daily number of new cases relative to the school closure scenario on July 5 (start of summer holidays) as a function of the relative transmissibility of younger children. (b) Projected ICU demand on August 1 relative to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency, as a function of the relative transmissibility of younger children. All pre-schools and primary schools are promptly reopened on May 11, followed by the reopening of middle and high schools on June 8 through four different protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*). Results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

Results obtained with 10% variations of the reproductive number during lockdown

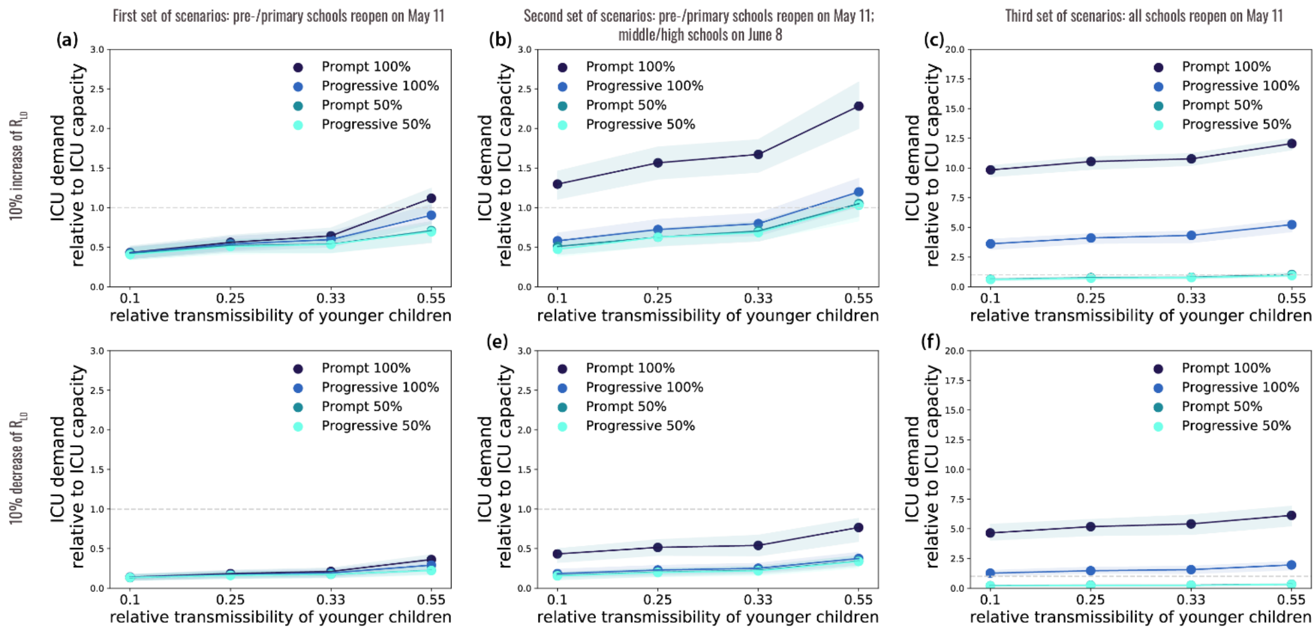

Figure S6. Simulated impact of reopening schools on ICU occupancy for 10% variations of the reproductive number. (a-c) Projected ICU demand on August 1 relative to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency, as a function of the relative transmissibility of younger children, for different reopening protocols. Results are obtained considering a 10% increase of the reproductive number during lockdown compared to estimate. (d-f) As (a-c) considering a 10% reduction of the reproductive number during lockdown compared to estimate. All results are obtained considering moderate social distancing interventions coupled with 50% case isolation.

Results obtained with moderate interventions and 25% case isolation

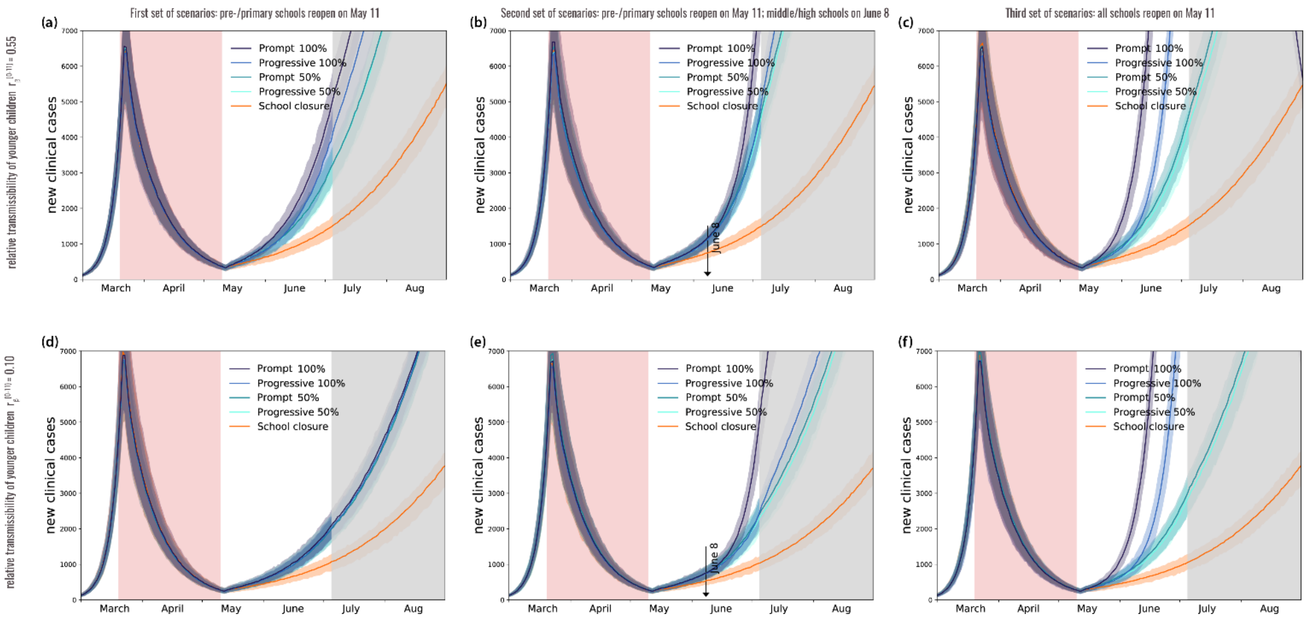

Figure S7. Simulated epidemic activity in scenarios with reopening of schools with 25% case isolation. (a-c) Simulated daily number of new clinical cases assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.55. (d-f) As (a-c) with $r_\beta^{[0-11)}$ =0.1. The red area indicates the lockdown phase; the grey area indicates summer holiday. Results are obtained considering moderate social distancing interventions coupled with 25% case isolation

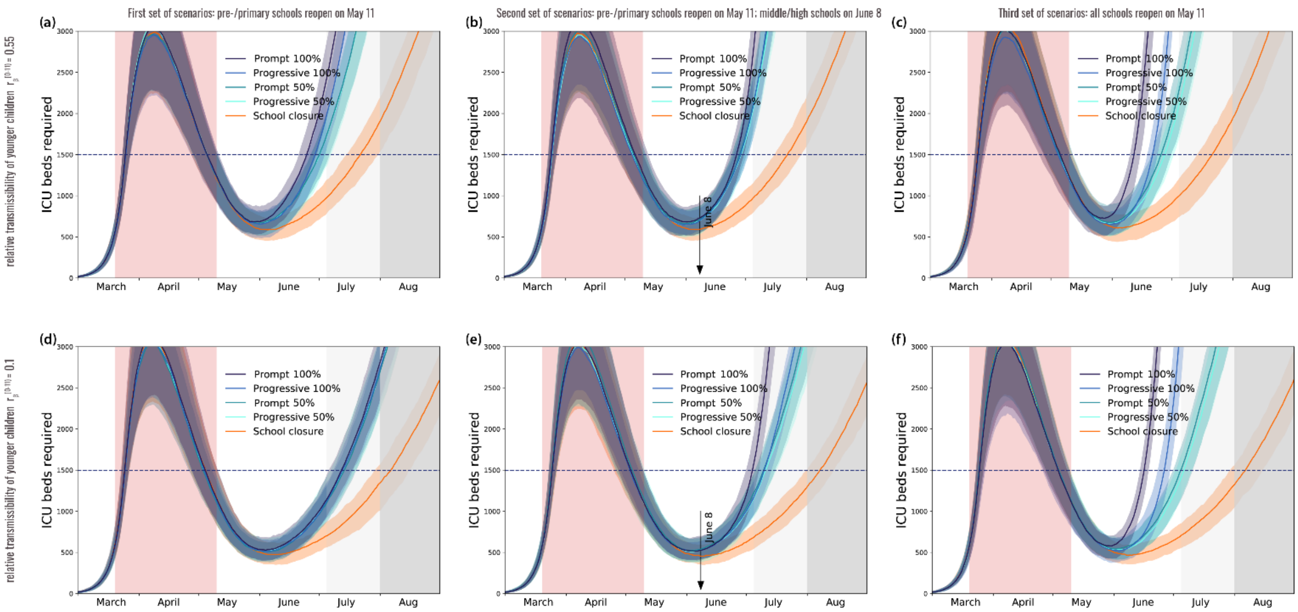

Figure S8. Simulated ICU occupancy in scenarios with reopening of schools with 25% case isolation. (a-c) Simulated demand of ICU beds assuming that only pre-schools and primary schools are reopened on May 11 through 4 different protocols (first set of scenarios, panel a), additionally considering the reopening of middle and high schools on June 8 (second set of scenarios, panel b), or assuming that all school levels reopen on May 11 (third set of scenarios, panel c). Four protocols (*Progressive (100% ,50%), Prompt (100%, 50%)*) are compared to the school closure scenario. Results are obtained for a relative transmissibility of younger children $r_\beta^{[0-11)}$ =0.55. (d-f) As in (a-c) for $r_\beta^{[0-11)}$ =0.55. The red area indicates the lockdown phase; the grey area indicates summer holiday (lighter grey in the month of July to show the delayed effect of the epidemic on ICU demand). Horizontal line refers to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency. Results are obtained considering moderate social distancing interventions coupled with 25% case isolation.

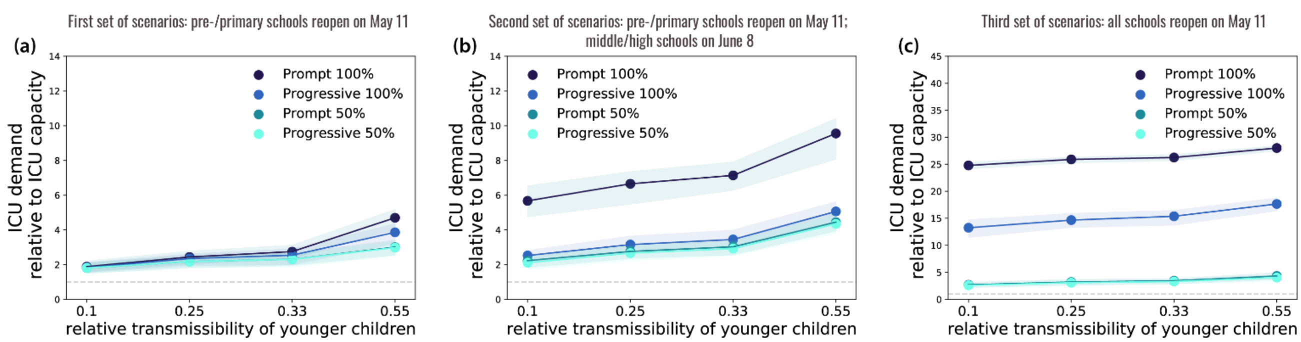

Figure S9. Simulated impact on ICU occupancy of reopening schools with 25% case isolation. (a-c) Projected ICU demand on August 1 relative to the foreseen 1,500-bed ICU capacity in the region restored after the first wave emergency, as a function of the relative transmissibility of younger children, for different reopening protocols. Results are obtained considering moderate social distancing interventions coupled with 25% case isolation.

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