

Influence of School Closure on COVID-19 Contaminations in Europe and Repercussions across Age Groups

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Abstract

TBD

1. Introduction

Since the onset of COVID-19, contradicting messages are circulating about the spread of the virus in schools. Sometimes presented as a safe environment (Falk et al., 2021; Walger et al., 2020), at other times designed as an aggravating factor of the pandemic (Lopez et al., 2020; Meuris et al., 2021), child care facilities and schools have been closed multiple times in most countries to protect the public health. However, the efficacy of school closure is still unknown and little is known about how COVID-19 Cases spread across age cohort and especially from the younger cohort being at school to older cohorts including parents, grand parents and relatives. Some evidence show that school is an influential environment where the virus is likely to spread. Once contaminated at school, a common spread believe is that the children and teenagers will then contaminate their parents. Therefore, among the political actions to stop the spread of COVID-19, the closure of primary and secondary schools was widely adopted worldwide. This research aims to investigate 1) the effect of school closure on the evolution of COVID-19 cases and 2) the temporal relationship between the rise of cases in children and teenagers with the rise of cases of older age group.

1.1. Influence of School Closure

One of the strongest assumption of government actions is that by reducing social contact will reduce the spread of the virus. Therefore, it is legitimate to believe that by closing schools, a reduction of the contaminations would be

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observed in the younger age groups. However, the efficiency of school closure on the reduction of COVID-19 cases is still questioned. While some research have observed that school closures contribute to limit or to reduce the growth rate of confirmed cases after implementation (Stage et al., 2021; Sugishita, 2020), other did not observe a change in the evolution of COVID-19 cases (Chang et al., 2020; Iwata et al., 2020). For instance, a controlled comparison between similar localities in Japan with schools closed and school open did not revealed any evidence that school closures reduced the spread of COVID-19 (Fukumoto et al., 2021). If the school closure had a real impact on the evolution of confirmed COVID-19 cases, it should be possible to observe a decrease or a least an inflection in the trend of its evolution among younger age groups.

1.2. Causal Relationship Between Age Groups

A second implicit believe regarding the effect of school closure on the spread of COVID-19 is that school not only has an effect on to the spread of the virus in children and teenagers but also has a knock-on effect on the spread of the virus in older age groups also called Secondary Attack Rate (SAR). The contaminated children and teenagers would bring the virus back at home and, then, they will contaminate their parents and relatives. For example, a research investigating the contamination in the household network not only revealed an exceptional high rate of secondary contamination but also that these contamination happened when the school were closed (Soriano-Arandes et al., 2021).

Despite being reported in several clinical and epidemiological studies (Siebach et al., 2021; Zhen-Dong et al., 2020), multiple research have shown that the SAR from children to household members was, in fact, lower than expected (Heavey et al., 2020; Hoek et al., 2020; Kim et al., 2021; Ludvigsson, 2020). However, the SAR of children and teenagers to the household member is likely to be age-dependent, with difference between infants, primary and secondary school children, and college students (Gras-Le Guen et al., 2021). If a secondary transmission from children and teenagers to household member has a significant influence, then a temporal causality relationship between their evolution should be observed.

2. Method

2.1. Observations

2.1.1. COVID-19 cases per age group

The number of COVID-19 cases per age group has been taken from the COVerAGE-DB project (Riffe et al., 2021). The COVerAGE-DB project consists in 3 data files: an “Input” data file which collects the official COVID-19 cases from 117 countries, the “Output_5” data file which is a projection of COVID-19 cases by group of 5 years, and the “Output_10” data file which is a projection of COVID-19 cases by group of 10 years. For our analyses we have used the “Output_5” which deals with the heterogeneity of countries’ reporting format by using spline approximations when the data for this age bracket

is not available for a country. Therefore, it allows a precise analysis between age groups under 24 while age groups of 25 and above are reduced to 10 year brackets and groups above 64 concatenated all together.

In order to cross validate the data of obtained after spline approximations, a comparison with the data published by the “World health organization COVID-19 data” (2022) reveals perfect similarities.

The original data consist in 14089320 observations of 10 variables (117 distinct country, region within the country, an unique observation code, the date of the observation, the gender which can be male, female or both, the age bracket by 5 years from 0 to 100, a confirmation of the age interval for each bracket, the total number of cases so far, the total number of deaths and the total number of tests performed) from February 16, 2020 to January 20, 2022.

After removing countries with missing and inconstant values, only 22 are suitable for the data analyses. However, in order to focus this analysis to geographically and culturally comparable countries, only 12 European countries are kept: Austria, Belgium, Bulgaria, Croatia, Estonia, France, Germany, Greece, Netherlands, Portugal, Slovakia, and Spain.

The observations are reported in terms of total number of COVID-19 cases from the start to the pandemic. Consequently, the daily number of cases at a specific date n_t is calculated with the difference between the total cases at a date t and the total cases at a date $t - 1$ (i.e., derivative 1). In addition the change in daily number of cases n_t between n_t and n_{t-1} has also been calculated (i.e., derivative 2).

2.1.2. School closure

The information regarding the school closure on a day by day basis is provided by the “UNESCO global education coalition” (2022). For each day, in each country, the status of the schools is indicated as fully open, partially open, closed due to COVID-19, or closed due to an academic break. Because it would be difficult to measure the effect of schools closure at a country level when schools are partially closed, on closures due to COVID-19, or due to an academic break are considered. Indeed, both are considered as closure at a country wide level.

2.2. Data Analysis

2.2.1. Generalised Additive Model

The effect of school closure on the trend of daily COVID-19 cases is analysed for each country. Periods of closure longer than 21 days are compared for 28 days regardless if the schools opened or not after 21 days.

A Generalised Additive Model (or GAM) using the R package *mgcv* (Wood, 2017) is fitted on the daily COVID-19 cases to test the hypothesis of a significant non-linear evolution of cases among age groups from 0 to 4, from 5 to 9, from 10 to 14, from 15 to 19, and from 20 to 24. The model also estimates the overall non-linear effect by country taking into account the interaction between age groups and countries as random intercepts and the interaction between time, countries and period of closure as random effects (Eq 1).

By estimating the degree of smoothness of a Bayesian spline smoothing using restricted fast maximum likelihood estimation (Wood, 2011), GAM identifies dynamic patterns underlying the evolution of COVID-19 cases reported while taking into account the random effect of different age groups and countries as follows:

$$n_{tgc} = \alpha_{gc} + f(\text{closure}_{tg}) + f(\text{closure}_{tc}) + a_{tcp} + \epsilon_{tgc} \quad (1)$$

where t is the date corresponding to the confirmed COVID-19 cases, g is an age group among the 10 age groups investigated, c is a country among the 12 European countries selected, and p is a specific period of closure. n_{tgc} represents the confirmed COVID-19 cases assuming a negative binomial distribution for the fitting (Loader, 2006). The response variable n_{tgc} includes a specific intercept for each age group and each country (α_{gc}). A smooth effect over time $f(\text{closure}_{tg})$ is applied to model for each age group and a smooth effect over time $f(\text{closure}_{tc})$ is applied to model for each country (Eq 2 and 3). These smooth effect $f(\text{closure}_{tg})$ and $f(\text{closure}_{tc})$ are built up in basic components, called the basis functions $b_i(X_{tg})$ and $b_j(X_{tc})$, such that:

$$f(\text{closure}_{tg}) = \sum_{i=1}^k \beta_i \times b_i(X_{tg}) \quad (2)$$

$$f(\text{closure}_{tc}) = \sum_{j=1}^k \beta_j \times b_j(X_{tc}) \quad (3)$$

where the regression parameters β_i and β_j are estimated by penalized likelihood maximization.

The model also includes the random effects term $a_{tcp} = Zb_i$ where Z is a random effects matrix and b_i is a vector of random effects described by $b_i \sim N(0, D)$. In this, D represents a covariance matrix. The error term ϵ_{tcp} is assumed to be normally and independently distributed $\epsilon_{tcp} \sim N(0, \sigma^2)$.

2.2.2. Transfer Entropy

Transfer Entropy (TE) can be used to infer the temporal relationship between two time series X and Y . This measure indicates whether X can be used to reduce the uncertainty on the future of Y and, consequently, that X causes Y (Schreiber, 2000). As such, Granger causality is a special case of TE applied to times series that are jointly Gaussian distributed (Barnett et al., 2009). Therefore, TE is a more robust analysis of times series especially when applied to the impact of age cohort in pandemic transmission (Kissler et al., 2020).

The influence of the evolution in COVID-19 cases across all age groups is evaluated using Shannon's transfer entropy is given by:

$$T_{X \rightarrow Y}(k, l) = \sum_{x, y} p(x_{t+1}, x_t^{(k)}, y_t^{(l)}) \log \left(\frac{p(x_{t+1} | x_t^{(k)}, y_t^{(l)})}{p(x_{t+1} | x_t^{(k)})} \right) \quad (4)$$

where $T_{X \rightarrow Y}$ consequently measures the influence of the change dynamic from an age group X to another age group Y for every country (Eq 4).

The day-by-day difference in COVID-19 confirmed cases n_t is used to satisfy the stationary requirement for the calculation of Shannon's Transfer Entropy (Shannon, 1948). The Transfer Entropy analysis across all age group is done using the R package *RTransferEntropy* (Behrendt et al., 2019).

3. Results

Overall, the trend of confirmed COVID-19 cases follows similar patterns across the selected European countries with scales respecting the size of population in these countries (Figure 1). Indeed, the bigger the country, the higher the total number of COVID-19 cases.

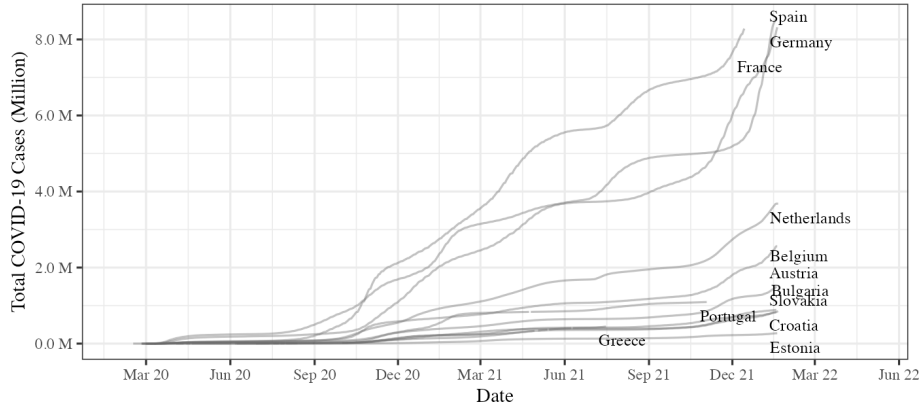


Figure 1: Cumulative COVID-19 cases number for selected European countries since the beginning of the pandemic. Source: COVerAGE-DB (Riffe et al., 2021).

The evolution of COVID-19 cases reveals some similarities across all age groups. However, the influence of each waves on the each groups has also some particularities (Figure 2). For example, the first wave was more important among the oldest age groups whereas the third wave was more important among the youngest age groups.

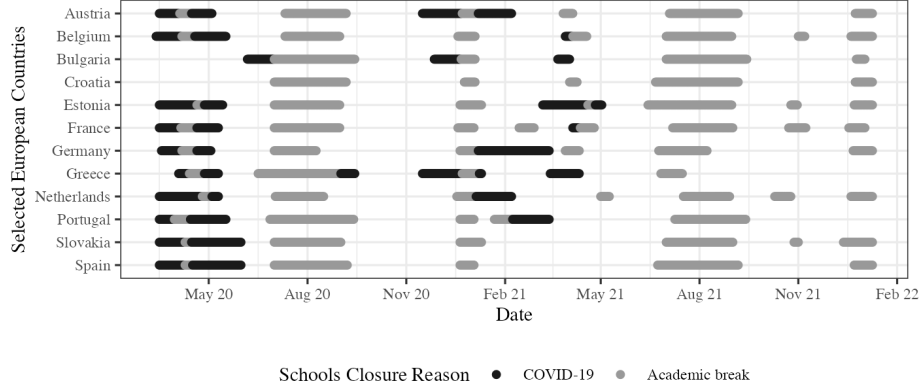


Figure 2: Periods of schools closure since the beginning of the COVID-19 pandemic for selected European countries and their reason: regular academic break vs. closure due to government decisions. Source: “UNESCO global education coalition” (2022).

In order to evaluate the shape of the trend in the numbers of COVID-19 cases reported after the three school closure longer than 21 consecutive days, a GAM was fitted taking into account numbers for 0 to 4, 5 to 9, 10 to 14, 15 to 19, and 20 to 24 year old across all the selected European countries. The obtained results satisfy the requirements to fit this model which explains 92.0% of the deviance in COVID-19 cases.

Overall, the results did not revealed a main effect of school closure at a country level for most of the selected European countries (Austria: $\chi^2(1) = 0$, $p = 0.986$; Belgium: $\chi^2(1) = 0.03$, $p = 0.872$; Bulgaria: $\chi^2(1) = 0.17$, $p = 0.682$; Croatia: $\chi^2(0) = 0.09$, $p = 0.999$; Estonia: $\chi^2(1) = 2.66$, $p = 0.103$; France: $\chi^2(1) = 3.17$, $p = 0.075$; Greece: $\chi^2(1) = 0.48$, $p = 0.487$; Netherlands: $\chi^2(1) = 0.01$, $p = 0.909$; Portugal: $\chi^2(1) = 1.7$, $p = 0.192$; Spain: $\chi^2(1) = 0.26$, $p = 0.608$) except for Germany ($\chi^2(7.93) = 7.26$, $p < 0.001$) and for Slovakia ($\chi^2(8.04) = 10.07$, $p < 0.001$).

When looking at the difference between age groups, results show no significant change in the evolution of cases until 19 year old (0 to 4: $\chi^2(1) = 0.21$, $p = 0.647$; 5 to 9: $\chi^2(1) = 0.2$, $p = 0.659$; 10 to 14: $\chi^2(1) = 0.17$, $p = 0.677$; 15 to 19: $\chi^2(1.95) = 1.18$, $p = 0.318$). However, the smooth term of the GAM is significant for 20 to 24 year old ($\chi^2(2.71) = 3.73$, $p = 0.008$), which indicates that the evolution of cases is not linear and, therefore, the school closure had a significant impact on the evolution of cases (Figure 3).

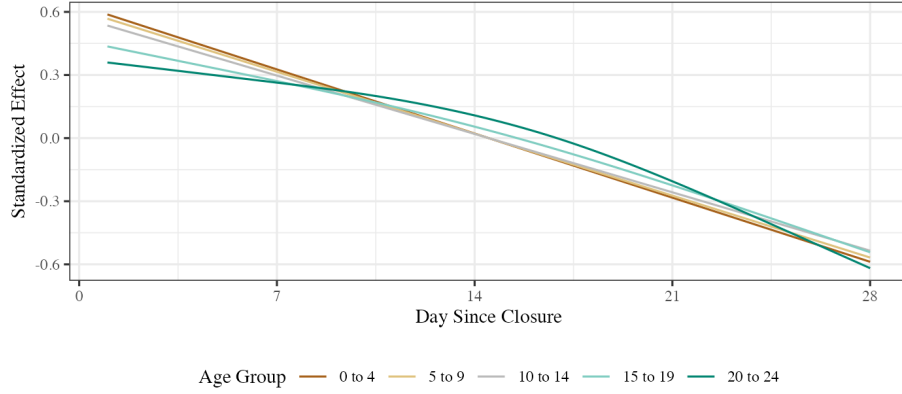


Figure 3: Standardized effect of the smooth term in Generalized Additive Model by age group.

Before the Transfer Entropy analysis, an Augmented Dickey-Fuller has been applied on each age group in order to insure that the daily changes in COVID-19 cases are stationary (see Appendix 1).

The results of the Transfer Entropy calculations between age groups for each of the 12 selected European countries are reported Figure 4. The first observation is the absence of symmetry between influencing age groups (i.e., X) and influenced age groups (i.e., Y). Indeed, the change in COVID-19 cases in some age groups are influenced by other age groups but they are not reciprocally influencing these age groups.

Additionally, to highlight differences and similarities between countries, a grid has been added to Figure 4: the upper left quadrant indicates how younger age cohorts are influencing older age cohorts, the bottom right quadrant indicates how older age cohorts are influencing younger age cohorts, finally lower left and upper right are indicating how younger or older age cohorts are influencing themselves. By analysing these quadrant it is possible to identify similar patterns across multiple countries. Indeed, it appears that Austria, Germany and the Netherlands have significantly higher TE coefficients in the upper left quadrant of the matrix, which indicate that the daily changes in COVID-19 cases number in younger cohorts is predicting the the daily changes in COVID-19 cases number in older cohorts. Alternatively, it appears that Austria, the Netherlands, Portugal and Spain have significantly higher TE coefficients in the lower right quadrant of the matrix, which indicate that the daily changes in COVID-19 cases number in older cohorts is predicting the the daily changes in COVID-19 cases number in younger cohorts.

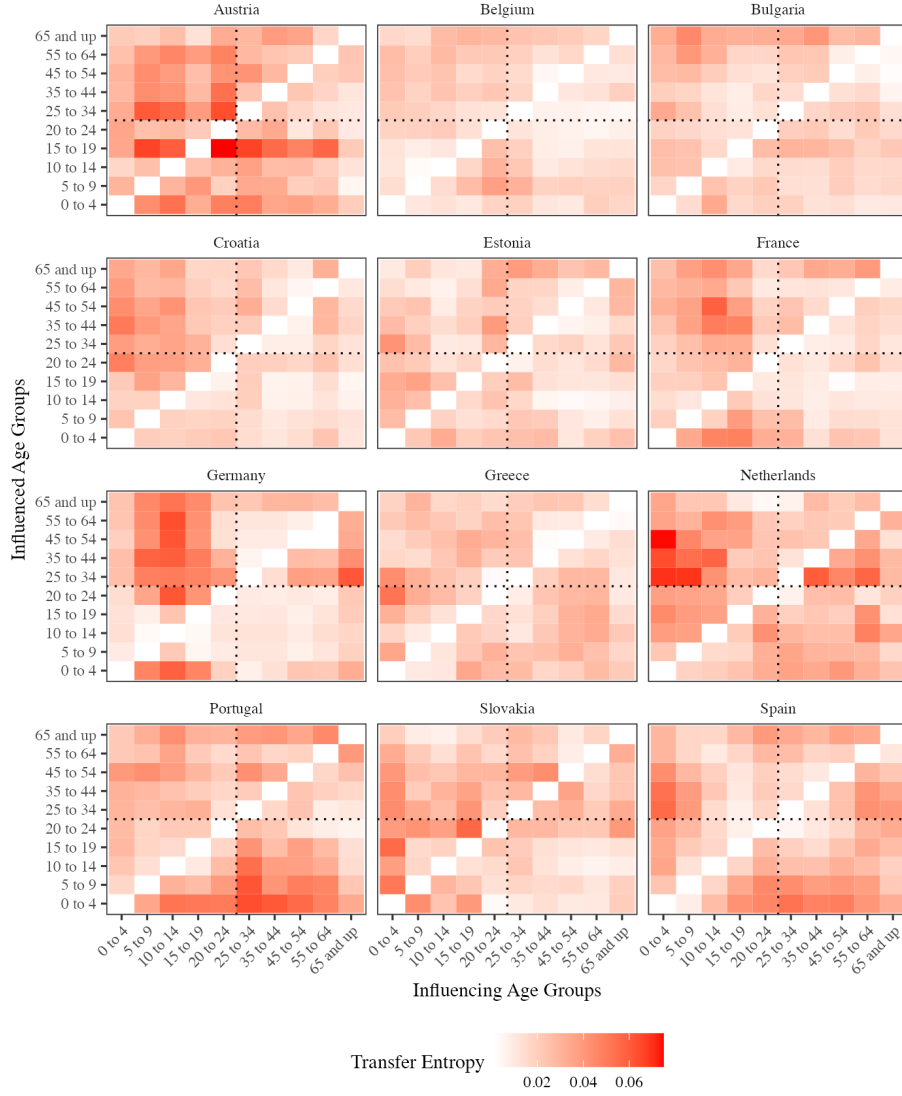


Figure 4: Matrix of Transfer Entropy coefficients according every age group combination for each of the selected European country. Age groups on the x-axis are influencing the age groups on the y-axis ($X \rightarrow Y$). The significance of each Transfer Entropy coefficient is provided in the Appendix 2.

4. Discussion & Conclusion

Knowledge about the transmission of the virus significantly improved with the amount of studies performed, especially in the case of how the virus behaves with children. From the early analyses showing that the virus was instantness

in children (Li et al., 2020), the results has changed to more nuanced position which states that the spread of the virus in children is moderate.

This indicate mix results, while the school closure was ineffective in pre-primary, primary and secondary levels (i.e., ISCED 0 to 3), the closure of tertiary levels (i.e., ISCED 5 to 8) had an impact on COVID-19 transmission. However, different pattern emerges according the selected European countries. Some have shown asymmetric patterns of influence between age groups while other did.

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