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Fast school closures correspond with a lower rate of COVID-19 incidence and deaths in most countries

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ABSTRACT

School closures have been used as one of the main nonpharmaceutical interventions to overcome the spread of SARS-CoV-2. Different countries use this intervention with a wide range of time intervals from the date of the first confirmed case or death. This study aimed to investigate whether fast or late school closures affect the cumulative number of COVID-19 cases or deaths. A worldwide population-based observational study has been conducted and a range of attributes were weighted using 10 attribute weighting models against the normalized number of infected cases or death in the form of numeric, binominal and polynomial labels. Statistical analysis was performed for the most weighted and the most common attributes of all types of labels. By the end of March 2021, the school closure data of 198 countries with at least one COVID-19 case were available. The days before the first school closure were one of the most weighted factors in relation to the normalized number of infected cases and deaths in numeric, binomial, and quartile forms. The average of days before the first school closure in the lowest quartile to highest quartile of infected cases (Q1, Q2, Q3 and Q4) was −6.10 [95% CI, −26.5 to 14.2], 9.35 [95% CI, 2.16 to 16.53], 17.55 [95% CI, 5.95 to 29.15], and 16.00 [95% CI, 11.69 to 20.31], respectively. In addition, 188 countries reported at least one death from COVID-19. The average of the days before the first school closure in the lowest quartile of death to highest quartile (Q1, Q2, Q3 and Q4) was −49.4 [95% CI, −76.5 to −22.3], −10.34 [95% CI, −30.12 to 9.44], −18.74 [95% CI, −32.72 to −4.77], and −12.89 [95% CI, −27.84 to 2.06], respectively. Countries that closed schools faster, especially before the detection of any confirmed case or death, had fewer COVID-19 cases or deaths per million of the population on total days of involvement. It can be concluded that rapid prevention policies are the main determinants of the countries' success.

1. Introduction

Nonpharmaceutical interventions have been widely used to reduce COVID-19 transmission since the beginning of the pandemic. Among them, school closures were one of the most widespread approaches [1]. The United Nations Educational, Scientific, and Cultural Organization (UNESCO) has provided a dataset for global monitoring of school closures due to COVID-19. Because of the availability and comprehensiveness of the data, analyzing and discovering the pattern of this data seems useful. Regarding the fact that school closures have social and educational implications for children and their families, the application of this pattern discovery must be carefully considered [2].

Some studies have shown that school closures reduce the rate of virus reproduction [3–9]. It has been reported that the lockdown or other nonpharmaceutical interventions can decrease the incidence and mortality of COVID-19, but reducing inhibitory rules reverses the virus epidemic in communities [10,11]. On the other hand, some articles emphasize the speed of countries' response to the pandemic [12–15]. In this study, we scan global school closures over 1 year to evaluate how school closures can affect COVID-19 cases and deaths.

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2. Methods

2.1. Data collection

A cumulative number of COVID-19 cases and deaths, from the beginning of the pandemic to the end of March 2021, was taken from World Health Organization (WHO) [16]. Data on school closures across the world was achieved from the UNESCO website [17]. The population size of each country was obtained from the Worldometers website [18].

2.2. Preparation of dataset

The total number of COVID-19 cases or deaths per million of the population in total days of involvement was used as a numeric label. RapidMiner Studio (9.9) was used to convert this label to nominal labels through scaling and categorizing them into two groups (below median & above median) or quartiles.

A range of attributes including School Closure (SC), Partially Open (PO), days before the first SC, days before the first PO, number of uses of SC, number of uses of PO, the ratio of SC to total days of involvement, the ratio of PO to total days of involvement, and the ratio of both SC and PO to total days of involvement were used. SC shows the number of days that schools are closed due to COVID-19 or/and an academic break. PO shows the number of days that schools are partially open. Days before the first SC or PO indicate the days between the first case or death and the first use of SC or PO (Negative values mean that schools have been closed before any case or death). The number of uses of SC or PO represents that these rules were applied in how many intervals in each country (Table 1).

All attributes were scanned for all countries, territories, or areas where at least one case or death was reported in WHO reports, and also their school data was available in the UNESCO dataset. In summary, 198 countries, territories, or areas with at least 1 reported case and 188 countries, territories, or areas with at least 1 reported death were studied.

2.3. Comparing different labels, attribute weighting and attribute-selection

In order to avoid the effect of label type (numeric or nominal, median or quartile, and cases or deaths) on final results, all types of labels were considered and all attributes were studied for each label type. Attribute weighting carried out for each label using Information Gain, Information Gain Ratio, Rule, Deviation, Chi-squared statistic, Gini Index, Uncertainty, Relief, Support Vector Machine, and Principal Component Analysis algorithms (RapidMiner Studio (9.9), as previously described [19,20]. These algorithms calculate the weight of attributes according to the label variable. The higher the weight of an attribute, the more relevant it is. All weights are normalized in the range 0–1. All attributes with an average weight greater than or equal to 0.2 were selected as the most important attributes. Using bioinformatics web tool (http://bioinformatics.psb.ugent.be/webtools/Venn/), common important attributes in all types of labels were short-listed for further analysis (Fig. 1).

Table 1
The list of all labels and attributes. Cases or deaths mean the total number of COVID-19 cases/deaths per million of the population in total days of involvement. Description of each attribute is given in the text (methods) in detail.

Labels	Attributes
Numeric (cases)	School Closure (SC)
Numeric (deaths)	Partially Open (PO)
Binomial (median of cases)	Days before the first SC
Polynomial (Quartile of cases)	Days before the first PO
Binomial (median of deaths)	Number of uses of SC
Polynomial (Quartile of deaths)	Number of uses of PO
	The ratio of SC to days
	The ratio of PO to days
	The ratio of SC and PO to days

2.4. Descriptive Statistics of the selected attribute

Descriptive Statistics include a count of countries in each quartile or group, mean of days before the first school closure, standard error mean (SE Mean) of days before the first school closure, standard deviation (StDev) of days before the first school closure, and coefficient variance of days before the first school closure was obtained for the selected attribute of each label, using Minitab 16 package [21,22] (Tables 2 and 3). Moreover, the Tukey test was taken using the same package [23,24].

3. Results

3.1. The most important attributes

Most weighted attributes of each label include a numeric label for both cases and death (number of cases or deaths per million of the population in total days of involvement), binomial label for both cases and death (based on median), and polynomial label for both cases and death (based on quartiles) were scanned. As shown in Fig. 1, School closures and days before school closures are the most common attributes of all labels. Due to the complexity of the figure, it is divided into two figures.

3.2. Descriptive statistical analysis

Based on descriptive statistical analysis, significant results were observed in the attribute of days before school closure, therefore, only this attribute is discussed in this paper. Moreover, to avoid confusion, data of cases and deaths are presented separately in further analysis.

The first quartile (Q1) represented the lowest number of cases or deaths per million of the population in total days of involvement, the second quartile (Q2) showed the second-lowest number of cases or deaths per million of the population in total days of involvement, third quartile (Q3) represented the second-highest number of cases or deaths per million of the population in total days of involvement and fourth quartile (Q4) showed the highest number of cases/deaths per million of the population in total days of involvement. Also, the below-median group indicated the lowest number of cases or deaths per million of the population in total days of involvement, and the above-median represented the highest number of cases or deaths per million of the population in total days of involvement. In the group of cases, quartiles 1 and 4 each contained 50 countries, and quartiles 2 and 3 each contained 49 countries. In the group of deaths, each quartile contained 47 countries.

The days before the first school closure showed the interval between the first reported cases or deaths and the date of the first full school closure. Negative values of this attribute indicated school closures before any confirmed reported cases or deaths in each country (fast responses). Zero values represented school closures on the same day of the first confirmed reported cases or deaths in each country. Positive values showed school closures after the first confirmed reported cases or deaths in each country (late responses).

3.3. COVID-19 cases

As shown in Fig. 2, many countries in Q1 and Q2 responded faster in full closure of their schools before any confirmed COVID-19 cases (negative values of the attribute of days before the first school closure). In contrast, 43 and 45 countries responded late in Q3 and Q4, respectively, in full closure of their schools before any confirmed reported cases (positive values of the attribute of days before the first school closure). The mean of days before the first school closure in Q1, Q2, Q3, and Q4 were −6.10, 9.35, 17.55, and 16.00 respectively (Table 2). These values are statistically significant based on the Tukey test with a P-value

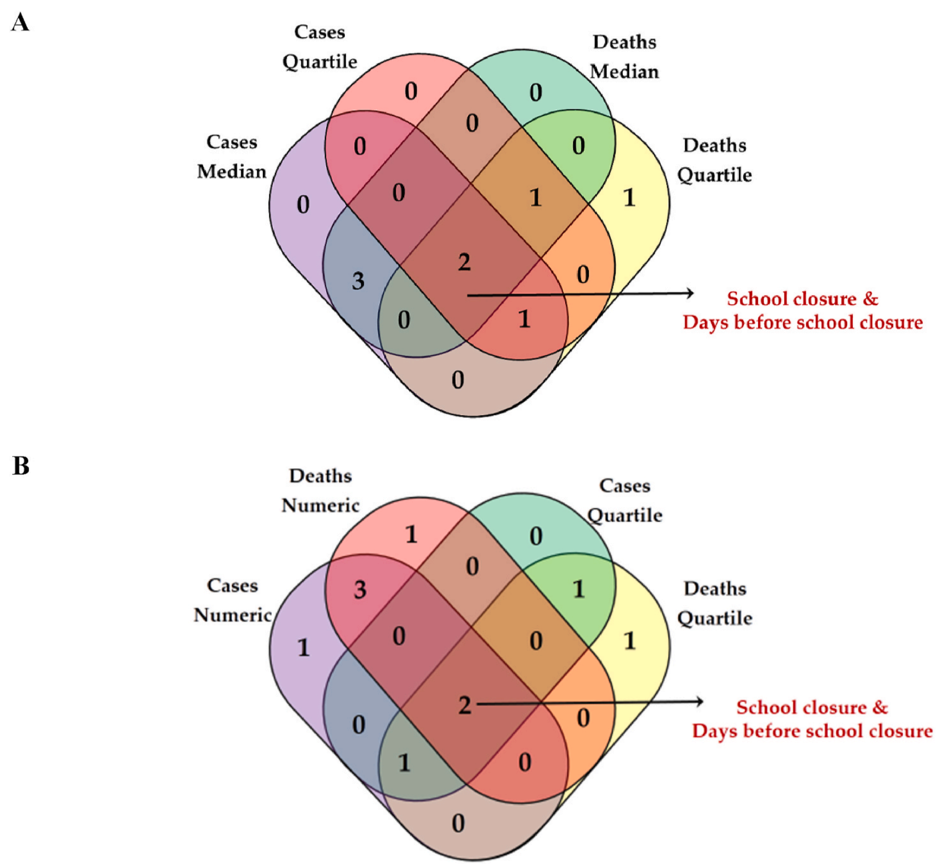

Fig. 1. Common important attributes of all binomial (based on median), polynomial (based on quartile), and numeric labels for both cases and deaths. A) Intersection of Cases-Median, Death-Median, Cases-Quartile, Death-Quartile labels. B) Intersection of Cases-Numeric, Death- Numeric, Cases-Quartile, Death-Quartile labels.

Table 2
Descriptive statistics for days before the first school closures as a variable in each quartile for both cases and deaths.

Group	Count of countries in each quartile	Mean of Days before the first school closures	SE Mean of Days before the first school closures	StDev of Days before the first school closures	CoefVar of Days before the first school closures	P-value
Q1-cases	50	−6.1	10.1	71.7	−1167.09	0.03
Q2-cases	49	9.35	3.57	25.02	267.70	
Q3-cases	49	17.55	5.77	40.39	230.13	
Q4-cases	50	16.00	2.14	15.16	94.73	
Q1-deaths	47	−49.4	13.5	92.4	−187.08	0.019
Q2-deaths	47	−10.34	9.83	67.36	−651.46	
Q3-deaths	47	−18.74	6.94	47.59	−253.89	
Q4-deaths	47	−12.89	7.43	50.92	−394.93	

Quartile 1 (Q1) is the lowest number of cases/deaths per one million population per total days of involvement, quartile 2 (Q2) is the second-lowest number of cases/deaths per one million population per total days of involvement, quartile 3 (Q3) is the second-highest number of cases/deaths per one million of population per total days of involvement and quartile 4 (Q4) is the highest number of cases/deaths per one million of population per total days of involvement.

of 0.03.

Moreover, based on the median number of cases per million of the population in total days of involvement, many countries in the below-median group have responded more quickly in full closure of their schools before any confirmed reported cases (negative values of the attribute of days before the first school closure). In contrast, 88 countries in the above-median group delayed in full closure of their schools before any confirmed reported cases (positive values of the attribute of days before the first school closure). The mean of the attribute of days before the first school closure in the below-median group and the above-median group were 1.53 and 16.77, respectively (Table 3). These values were statistically significant based on the Tukey test with a P-value of 0.015.

Generally, it can be concluded that many successful countries with a lower number of cases per million of the population in total days of involvement have closed their schools before any confirmed reported cases. In other words, 75% of countries that have closed their schools before any confirmed reported cases were in Q1 and Q2 and only 25% of them were in Q3 and Q4 (Table 4).

Table 3
Descriptive statistics for days before the first school closures as a variable in each median for both cases and deaths.

Group	Count of countries in each group	Mean of Days before the first school closures	SE Mean of Days before the first school closures	StDev of Days before the first school closures	CoefVar of Days before the first school closures	P-value
Below median-cases	99	1.53	5.44	54.17	3551.76	0.015
Above median-cases	99	16.77	3.04	30.24	180.35	
Below median-deaths	94	−29.86	8.54	82.77	−277.19	0.159
above median-deaths	94	−15.82	5.06	49.11	−310.42	

Below median is the lowest number of cases/deaths per one million of population per total days of involvement and above-median is the highest number of cases/deaths per one million of population per total days of involvement.

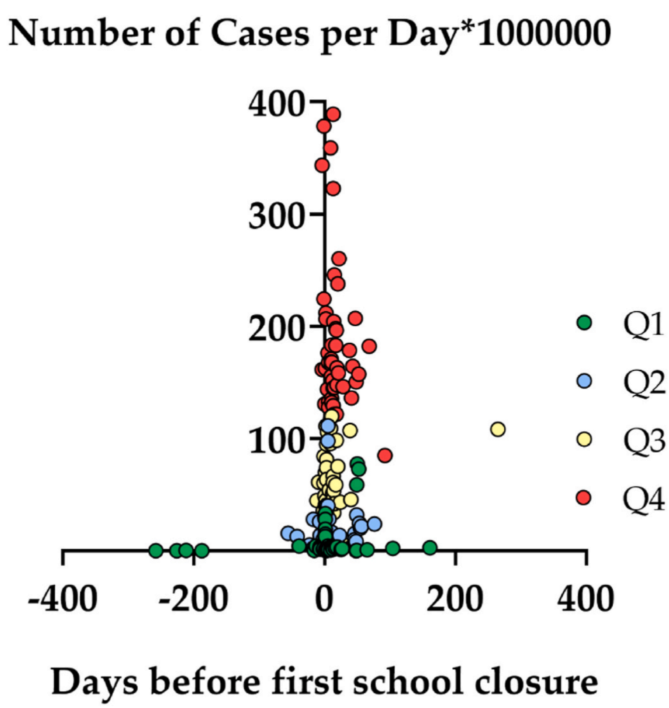

Fig. 2. The number of cases per million of population per day. Quartile 1 (Q1) is the lowest number of deaths per one million population per total days of involvement; quartile 2 (Q2) is the second-lowest number of deaths per one million population per total days of involvement; quartile 3 (Q3) is the second-highest number of deaths per one million of population per total days of involvement, and quartile 4 (Q4) is the highest number of deaths per one million of population per total days of involvement. Days before the first school closure shows gap days between the first reported deaths and the date of school closure (fast responses).

Table 4
Distribution of countries that have closed their schools before any confirmed reported cases in each quartile.

Quartiles	Q1	Q2	Q3	Q4
Countries	16	11	5	4
Countries%	44.4%	30.6%	13.9%	11.1%
Total %	75%		25%	

Quartile 1 (Q1) is the lowest number of cases per one million population per total days of involvement, quartile 2 (Q2) is the second-lowest number of cases per one million population per total days of involvement, quartile 3 (Q3) is the second-highest number of cases per one million of population per total days of involvement and quartile 4 (Q4) is the highest number of cases per one million of population per total days of involvement.

3.4. COVID-19 deaths

As shown in Fig. 3, 41 countries in Q1 responded faster in full closure of their schools before any confirmed reported deaths (negative values of the attribute of the days before the first school closure). In contrast, countries in other quartiles responded in full closure of their schools at the same time (close to 0) or after (positive values of days before the first school closure) of confirmed reported deaths. The mean of days before the first school closure in Q1, Q2, Q3, and Q4 were −49.4, −10.34, −18.74, and −12.89 respectively (Table 2). These values are statistically significant based on the Tukey test with a P-value of 0.019.

Moreover, based on the median number of deaths per million of the population in total days of involvement, 75 countries in the below-median group responded faster (negative values of the attribute of the

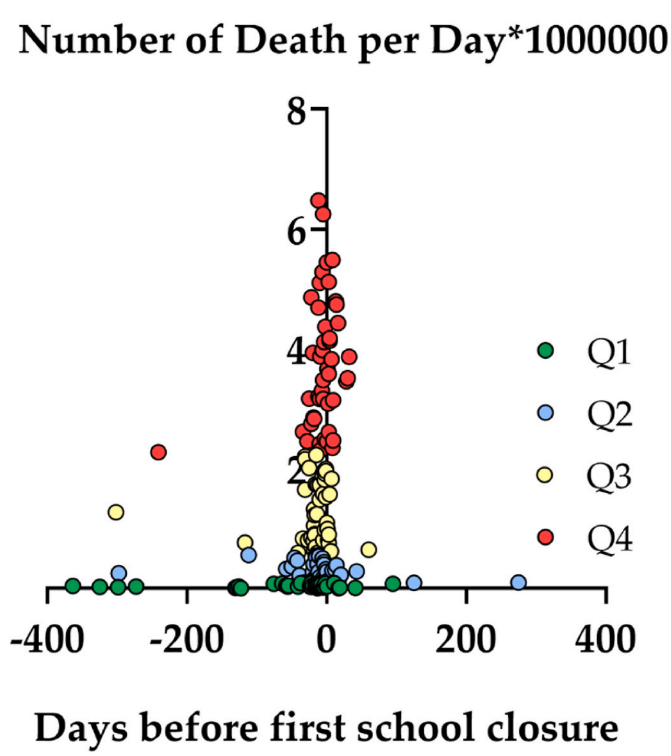

Fig. 3. The number of death per million of population per day. Quartile 1 (Q1) is the lowest number of deaths per one million population per total days of involvement, quartile 2 (Q2) is the second-lowest number of deaths per one million population per total days of involvement, quartile 3 (Q3) is the second-highest number of deaths per one million of population per total days of involvement and quartile 4 (Q4) is the highest number of deaths per one million of population per total days of involvement. Days before the first school closure shows gap days between the first reported deaths and the date of school closure (fast responses).

days before the first school closure) in full closure of their schools before any confirmed reported deaths. In contrast, 65 countries in the above-median group have responded by fully closure of their schools at the same time (close to 0) or after the first confirmed reported deaths. The mean of days before the first school closure in the below-median group and above-median group were 29.86 and −15.82, respectively (Table 3). These values are statistically significant based on the Tukey test with P-value of 0.159.

Generally, it can be concluded that many successful countries with a lower number of deaths per million of the population in total days of involvement have closed their schools many days before any confirmed reported deaths. Furthermore, 61.9% of countries that have closed their schools after the first confirmed reported deaths were in Q3 and Q4 and only 35.7% of them are in Q1 and Q2 (Table 5).

4. Discussion

The WHO declared COVID-19 as a pandemic on March 11, 2020 [16]. Due to the lack of any definite treatment or vaccine at the beginning of the outbreak, most countries applied various policies to overcome this pandemic. These policies are still ongoing in many regions due to the lack of sufficient vaccines. Some countries have started inhibitory rules after the detection of certain COVID-19 cases or deaths with different time gaps between the first reported cases or deaths and the date of COVID-19 restrictions. Some countries were more cautious and commenced COVID-19 restrictions even before identification of any confirmed cases or deaths in their own countries, such as Samoa, Vanuatu, Marshall Islands, and Solomon Islands that closed their schools due to COVID-19 [17].

Although it may seem that school closure is not a sufficient answer to overcome the pandemic, it has been introduced as one of the most effective strategies in diminishing the epidemic curve in each community [25–27]. Furthermore, it can be a good mirror to reflect part of the whole reaction of each country to the pandemic.

Many papers scanned the role of school closures or other non-pharmaceutical policies on the COVID-19 incidence and mortality rate in specific periods and countries. These papers stated that these policies have been effective in reducing the virus transmission but after reopening or relaxation of inhibitory rules, the number of cases starts to increase and the policies have impermanent effects [10,11,28–33]. On the other hand, some other papers emphasize the early application of school closures to reduce virus transmission [34,35]. In the current study, a simultaneous analysis of the effect of global school closures on both cumulative COVID-19 cases and deaths since the beginning of the pandemic by the end of March 2021 was carried out. Our results are almost in agreement with a recent publication in the US, which claimed that earlier school closures had the largest relative reduction in incidence and mortality [36].

Based on attribute weighting algorithms, school closure and days before the first school closure were found to be the most important attributes of all kinds of labels. Further statistical analysis revealed that the attribute of the days before the first school closure has a significant impact on the cumulative number of COVID-19 cases or deaths per million of the population in total days of involvement after 15 months. In brief, if countries had prevented the transmission of the viruses by the fast school closure before detection of any confirmed COVID-19 cases or deaths, they would be in successful groups. Our results are in line with other publications that claimed time and speed of nonpharmaceutical policies are determining factors [37,38].

5. Conclusion

The lower cumulative COVID-19 cases or deaths per million of population per total days of involvement are observed in the countries or regions that closed their schools faster or even before detection of any confirmed case or death by the end of March 2021. Also, school closure decreases the number of cases or deaths in different terms based on literature.

Table 5
Distribution of countries that have closed their schools after the first confirmed reported deaths in each quartile.

Quartiles	Q1	Q2	Q3	Q4
Countries	5	10	8	18
Countries%	11.9%	23.8%	19.00%	42.90%
Total %	35.7%		61.9%	

Quartile 1 (Q1) is the lowest number of deaths per one million population per total days of involvement, quartile 2 (Q2) is the second-lowest number of deaths per one million population per total days of involvement, quartile 3 (Q3) is the second-highest number of deaths per one million of population per total days of involvement and quartile 4 (Q4) is the highest number of deaths per one million of population per total days of involvement.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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