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ORIGINAL RESEARCH

Covid-19 Social Distancing Interventions by Statutory Mandate and Their Observational Correlation to Mortality in the United States and Europe

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Purpose: Evaluate the correlation between statutory social distancing interventions and Covid-19 mortality independently in both the United States and Europe. The study is presented as a potential methodology to evaluate the effectiveness of statutory social distancing policy.

Patients and Methods: Twenty-seven states in the United States and, separately, 12 European countries were selected which had clearly defined and dated establishment of statewide or national mandates for social distancing measures from the Institute for Health Metrics and Evaluation (IHME) data. Mandated social distancing measures considered in this study include: School closures, Prohibition on mass gatherings, business closures, stay at home orders, severe travel restrictions, and closure of non-essential businesses. The state/country Covid-19 peak mortality rate (PMR) was defined as the initial averaged normalized maximum during which social distancing mandates were in effect. Mandate-days were defined as the total days legislative mandates were in place to the PMR.

Results: The normalized peak mortality rate in the US and in Europe did not demonstrate a statistically significant correlation to the total mandate days (R-squared=0.053, p=0.246, R-squared=2.4E-06, p=0.996). A significant correlation was found between normalized mortality rate and state/country population density (R-squared=0.524, p=0.00002, R-squared=0.397, p=0.0281).

Discussion: The analysis appears to suggest no mandate effective reduction in Covid-19 mortality rate to its defined initial peak when interpreting their mean-effect. A strong correlation to population density suggests human interaction frequency does affect the peak mortality rate.

Keywords: epidemiology, analysis, SARS-Cov-2, mortality-rate, social-distancing, orders

Introduction

Socially distancing policy has been theorized to effectively reduce the rate of transmission of contagious diseases.[1–3] Mandating social distancing within state jurisdictions the United States and countries in western Europe has been instituted to varying degrees during the Covid-19 pandemic. Reducing the maximum contagion transmission by mandating decreased social interactions has been theorized to reduce mortality by allowing for social/medical mobilization and proper resource allocation.[3–5] Verification of this theoretical model has not been demonstrated, except analyses demonstrating marginal social distancing effectiveness in delaying the peak infection.[6] The extensive global incidence of the

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Covid-19 pandemic and unique real-time record keeping presents an opportunity to evaluate the social distancing theory over a large population instituting considerably different social distancing measures. The purpose was to quantify the decrease in the infection/mortality or decrease in the maximum infection/mortality rate as a result of defined state mandated social distancing measures.

Patients and Methods

Data Collection

The study was conducted using the Institute for Health Metrics and Evaluation (IHME) openly published data on Covid-19 infections by individual states in the United States, to include daily infections/deaths as well as onset and discontinuation dates of state mandated social interaction interventions. A separate validating analysis was completed using IHME source information for individual European countries. As this was the primary source of information used for predictive modeling and setting public policy, it was chosen for its accuracy and regular updates.[7] The methods are discussed extensively in the available preprint manuscript: "Covid-19 Social Distancing Interventions by State Mandate and Their Correlation to Mortality".[8]

Mortality was chosen to define endpoint peaks and rates of change over registered infections within a state. Covid-19 registered infections are beset by inaccuracies due to: Inaccurate testing, testing frequency, asymptomatic patients, test availability, and regional variations in testing criteria. Individual states and developed countries routinely record accurately the cause and time of death. The analyses normalize for the state's or county's stage in the epidemiological infectious cycle by only accounting for mortality up to the initial peak mortality rate.

United States IHME data accessed on June 17, 2020 at 1900 EST was used to select all US states with more than a maximum mortality rate of 10 Covid-19 deaths per day. Separately, IHME data accessed on April 12, 2020 at 1900 EST was used to preliminarily select more than 10 sovereign European countries which fit into a geographic area of similar genomic constituency and indicated by WHO to have developed healthcare standards.[7] Selected states/countries were independent legal jurisdictions which enacted geographically universal preventive social distancing statutes on a specific date to include one of the six (6) possible mandates defined in the IHME website data set. States or countries excluded were not in the geography of Europe or the United States, low initial maximum death rate of less than 10, or did not universally enact statutes.

Considered forms of social mandates:

1. Public School Closures
2. Social Gathering Restrictions
3. Stay-at-Home Orders
4. Business Closures
5. Non-Essential Business Closures
6. Severe Travel Restrictions

All States and countries maintained all mandated social distancing measures through the end of the examination period (initial peak mortality rate) and none were excluded. Twenty-seven (27) States were included as listed in Table 1 and twelve (12) western European countries were included as listen in Table 2. All states/countries mandated social distancing universally across their respective territory of the 6 variations listed above on a specific date provided by the IHME data set accessed on June 17, 2020 and maintained them through their initial peak infection rate.[8]

The defined endpoints for the analysis included the date of the initial peak mortality rate in deaths per day for each state/country. A state's or country's peak mortality was defined as the highest recorded daily deaths over a seven-day moving-average which was followed by a seven-or-more day decline in mortality with no other discernable peaks (using the same criteria) at the time of accessing the data. The maximum daily mortality rate was used as an easily defined universal milestone in any infectious disease progression to examine the total viral mortality up to the maximum initial mortality rate during which mandates were continuously enacted.

Additionally, the maximum slope of the Covid-19 mortality was determined by evaluating the maximum of the derivative of the mortality curve. Specifically, this slope was defined as the total recorded mortality five days after the peak-mortality-rate minus the total recorded mortality five days before the peak-mortality-rate divided by the 10-day interval. Both the mortality-at

-peak and peak-mortality-rate were normalized by dividing by the population of the selected state/country.

Equation 1 Formula to calculate the estimate for the peak-mortality rate

$$\begin{matrix}Peak\\Mortality\\Rate\\Estimate\end{matrix} = \frac{\begin{pmatrix}Mortality\,5\,Days\\After\,Peak\end{pmatrix} - \begin{pmatrix}Mortality\,5\,Days\\Before\,Peak\end{pmatrix}}{10\,days}$$

All data were analyzed with Matlab and Microsoft Excel.[11] General linear mixed effects (GLME) modeling was used to examine combined effects of the multiple variables. Specifically, Microsoft Excel was used for the bivariate linear regressions and ANOVA summaries for both mortality-at-peak and peak-mortality-rate while Matlab was used to generate the 95% confidence interval bounds on those linear regressions as well as the separate multivariate GLME analyses.

The clinical study was conducted within the ethical principles contained in Declaration of Helsinki, Code of Federal Regulations (CRF), Obligations of Clinical Investigators (21 CFR 812). All data were public and anonymous so no IRB was needed.

Data Analysis

The study conducted two high-level bivariate analyses on this data: one for each output of interest – peak-mortality-rate (PMR) and mortality-at-peak (MAP) – against the total mandate days.[8] The total mandate days was defined as the summation from each form of social-mandate of the total number of days prior to the initial peak that form of social-mandate was implemented.[8]

Equation 2 Formula for Total Mandate Days were calculated from each form of social-mandate and the number of days prior to the initial peak the mandates were implemented.

$$\begin{aligned}Total\,Mandate\,Days &= Days^{SchoolClosure}_{PriorToPeak} + Days^{Gatherings}_{PriorToPeak}\\ &+ Days^{StayAtHome}_{PriorToPeak} + Days^{Business}_{PriorToPeak}\\ &+ Days^{NonEssentBus}_{PriorToPeak} + Days^{TravelRestrict}_{PriorToPeak}\end{aligned}$$

Also, bivariate analyses with the same response variables against population density were produced. Finally, two multivariate analyses were conducted. These multivariate analyses used the same response variables as in the previous bivariate studies.[8]

Equation 3 GLME model for peak-mortality-rate studied in the multivariate analysis.

$Peak\ Mortality\ Rate = \mu_{PMR}$	Overall mean peak mortality rate
$+\,\alpha_{StayAtHome} \cdot Days^{StayAtHome}_{PriorToPeak}$	Fixed-effect from stay-at-home orders
$+\,\alpha_{SchoolClosure} \cdot Days^{SchoolClosure}_{PriorToPeak}$	Fixed-effect from school closure
$+\,\alpha_{Gatherings} \cdot Days^{Gatherings}_{PriorToPeak}$	Fixed-effect from social gathering restrictions
$+\,\alpha_{Business} \cdot Days^{Business}_{PriorToPeak}$	Fixed-effect from general business closure
$+\,\alpha_{NonEssentBus} \cdot Days^{NonEssentBus}_{PriorToPeak}$	Fixed-effect from non-essential business closure
$+\,\alpha_{TravelRestrict} \cdot Days^{TravelRestrict}_{PriorToPeak}$	Fixed-effect from travel restrictions
$+\,\alpha_{GeneVar} \cdot PopDens$	Fixed-effect from population density
$+\,\alpha_{MedAge} \cdot MedianAge$	Fixed-effect from median age
$+\,\varepsilon_{PMR}$	Random Gaussian error

Equation 4 GLME model for mortality-at-peak studied in the multivariate analysis.

$Mortality\ at\ Peak = \mu_{MAP}$	Overall mean mortality at peak
$+\,\beta_{StayAtHome} \cdot Days^{StayAtHome}_{PriorToPeak}$	Fixed-effect from stay-at-home orders
$+\,\beta_{SchoolClosure} \cdot Days^{SchoolClosure}_{PriorToPeak}$	Fixed-effect from school closure
$+\,\beta_{Gatherings} \cdot Days^{Gatherings}_{PriorToPeak}$	Fixed-effect from social gathering restrictions
$+\,\beta_{Business} \cdot Days^{Business}_{PriorToPeak}$	Fixed-effect from general business closure
$+\,\beta_{NonEssentBus} \cdot Days^{NonEssentBus}_{PriorToPeak}$	Fixed-effect from non-essential business closure
$+\,\beta_{TravelRestrict} \cdot Days^{TravelRestrict}_{PriorToPeak}$	Fixed-effect from travel restrictions
$+\,\beta_{GeneVar} \cdot PopDens$	Fixed-effect from population density
$+\,\beta_{MedAge} \cdot MedianAge$	Fixed-effect from median age
$+\,\varepsilon_{MAP}$	Random Gaussian error

These models were then regressed onto the data from Tables 1 and 2. Note that where certain social distancing mandates were not implemented, the "Days Prior to Peak" values were coded as zero in modeling to avoid singular data matrices during the regression analysis.[8] The travel restrictions mandate were removed from the US analysis since no states implemented strict travel restrictions in the time of this study according to Table 1.

Results

Bivariate Analysis, MAP vs Total Mandate Days

Twenty-Seven US states were selected on June 17, 2020 to examine their collective correlation between standardized mortality and total mandate-days of state mandated social

http://doi.org/10.2147/POR.S298309

Table 1 Data on Population Density, Median Age, Social Mandate, and Covid-19 Mortality, and Covid-19 Maximum Mortality Rate on the 27 States in the USA Used in This Analysis. Covid-19 Data Was Obtained from IHME and Census Data.[7,9,10]

State	Date of Peak Death Rate	Mortality at Peak	Peak Mortality Rate	School Closure		Gathering Restrictions		Stay-at-Home Orders	
		[Deaths/ Million]	[Deaths/ Million/ Day]	Date Start	Mandate Days Before Peak	Date Start	Mandate Days Before Peak	Date Start	Mandate Days Before Peak
Arizona	14-May	83.1	2.34	16-Mar	59	30-Mar	45	30-Mar	45
California	26-Apr	43.5	2.84	19-Mar	38	11-Mar	46	19-Mar	38
Colorado	23-Apr	98.1	4.74	23-Mar	31	19-Mar	35	26-Mar	28
Conneticut	22-Apr	413	28.1	17-Mar	36	12-Mar	41	N/A	0
Florida	18-Apr	32.9	2.16	17-Mar	32	3-Apr	15	3-Apr	15
Georgia	18-Apr	61.8	3.45	18-Mar	31	24-Mar	25	3-Apr	15
Illinios	11-May	279.5	8.29	17-Mar	55	13-Mar	59	21-Mar	51
Indiana	22-Apr	102.1	3.15	19-Mar	34	12-Mar	41	25-Mar	28
Iowa	11-May	116.6	4.46	4-Apr	37	17-Mar	55	N/A	0
Louisiana	12-Apr	191.7	13.6	16-Mar	27	13-Mar	30	23-Mar	20
Maryland	23-Apr	133.8	9.26	16-Mar	38	16-Mar	38	30-Mar	24
Massachusetts	26-Apr	410	25.1	17-Mar	40	13-Mar	44	N/A	0
Michigan	15-Apr	195.9	14.4	16-Mar	30	13-Mar	33	24-Mar	22
Minnisota	11-May	103.7	4.05	18-Mar	54	28-Mar	44	28-Mar	44
Mississippi	18-May	178.3	5.25	19-Mar	60	24-Mar	55	27-Apr	21
Missouri	24-Apr	43.6	2.45	23-Mar	32	23-Mar	32	6-Apr	18
New Jersey	18-Apr	445.7	32.2	18-Mar	31	16-Mar	33	21-Mar	28
New York	11-Apr	568.1	50.8	18-Mar	24	12-Mar	30	22-Mar	20
North Carolina	11-May	54.5	1.63	14-Mar	58	14-Mar	58	3-Apr	38
Ohio	11-May	117.4	3.76	16-Mar	56	12-Mar	60	23-Mar	49
Pennsylvania	30-Apr	191	9.92	17-Mar	44	1-Apr	29	4-Apr	26
Rhode island	18-May	402.9	13.4	16-Mar	63	17-Mar	62	7-Apr	41
South Carolina	1-May	46.9	1.92	16-Mar	46	18-Mar	44	7-Apr	24
Texas	8-May	34.8	1.05	19-Mar	50	21-Mar	48	9-Apr	29
Virginia	8-May	91.4	3.31	16-Mar	53	15-Mar	54	30-Mar	39
Washington	8-Apr	59	2.63	13-Mar	26	11-Mar	28	23-Mar	16
Wisconsin	11-Apr	22.8	1.86	18-Mar	24	17-Mar	25	25-Mar	17

Note: Fields with "N/A" indicate the country did not implement that particular form of social mandate in the timeframe observed in this study.

distancing directives. All states maintained social distancing directives through the study endpoint.[7] States were found to have a significant diversity in total mandated intervention over time (mean = 171 total-mandate-days, std-dev = 50 total-mandate-days). The total population studied was 292 million. All states had statistically similar age distributions (mean = 38.6 years-old, std-dev = 1.5 years-old). The population density varied significantly (mean = 304 Pop./square mile, std-dev = 306 Pop./square mile)

Results for the US state bivariate analysis of mortality-at-peak (MAP) against total mandate days were analyzed. The correlation of the standardized mortality-at-peak with total-mandate-days of social-distancing mandates prior to the peak was found to be statistically insignificant (R-squared = 2E-06 with p-val = 0.9946).

Separately, twelve similar western European sovereign countries were pre-selected on April 12, 2020 to examine their collective correlation between standardized mortality and total mandate-days of state directed social distancing directives. All countries maintained social distancing directives through the study endpoint on May 1, 2020.[7] Countries were found to have a significant diversity in total mandated intervention over time (mean = 58 total-mandate-days, std-dev = 30.6 total-mandate-days). The total population studied was 183 million. All countries had statistically similar age distributions (mean = 41.8 years-old, std-dev = 1.23 years-old). The total standardized mortality at the peak (MAP) per European country also exhibited no statistical correlation to the total mandate days (R-squared = 0.004, p=0.85).

Business Closures		Non-Essential Business Closures		Travel Restrictions		Total Mandate Days	Covid-19 Data Sources	Average Population Density	Median Age
Date Start	Mandate Days Before Peak	Date Start	Mandate Days Before Peak	Date Start	Mandate Days Before Peak	[Days]		[Persons/sq. mi.]	[Years]
30-Mar	45	30-Mar	45	N/A	0	239	IHME	64.08	38.2
19-Mar	38	19-Mar	38	N/A	0	198	IHME	253.64	37
17-Mar	37	26-Mar	28	N/A	0	159	IHME	55.56	37.1
16-Mar	37	23-Mar	30	N/A	0	144	IHME	736.27	41.1
17-Mar	32	N/A	0	N/A	0	94	IHME	399.96	42.5
24-Mar	25	N/A	0	N/A	0	96	IHME	184.61	37.1
16-Mar	56	21-Mar	51	N/A	0	272	IHME	228.24	38.6
16-Mar	37	24-Mar	29	N/A	0	169	IHME	187.91	37.9
17-Mar	55	17-Mar	55	N/A	0	202	IHME	56.48	38.5
17-Mar	26	22-Mar	21	N/A	0	124	IHME	107.60	37.5
16-Mar	38	23-Mar	31	N/A	0	169	IHME	622.80	39.1
17-Mar	40	24-Mar	33	N/A	0	157	IHME	883.65	39.6
16-Mar	30	23-Mar	23	N/A	0	138	IHME	176.64	39.9
17-Mar	55	N/A	0	N/A	0	197	IHME	70.83	38.3
24-Mar	55	27-Apr	21	N/A	0	212	IHME	63.43	38
23-Mar	32	N/A	0	N/A	0	114	IHME	89.28	38.9
16-Mar	33	21-Mar	28	N/A	0	153	IHME	1207.77	40.1
16-Mar	26	22-Mar	20	N/A	0	120	IHME	412.80	39.2
17-Mar	55	3-Apr	38	N/A	0	247	IHME	215.72	39.1
15-Mar	57	30-Mar	42	N/A	0	264	IHME	286.07	39.5
18-Mar	43	23-Mar	38	N/A	0	180	IHME	286.12	40.8
17-Mar	62	N/A	0	N/A	0	228	IHME	1024.72	40.1
18-Mar	44	N/A	0	N/A	0	158	IHME	171.28	39.9
21-Mar	48	N/A	0	N/A	0	175	IHME	111.00	35
17-Mar	52	24-Mar	45	N/A	0	243	IHME	216.14	38.6
16-Mar	23	25-Mar	14	N/A	0	107	IHME	114.59	37.8
17-Mar	25	25-Mar	17	N/A	0	108	IHME	107.51	39.8

Bivariate Analysis, PMR vs Total Mandate Days

The slope of the standardized mortality per European country or peak mortality rate (PMR) did not significantly correlate to the total mandate days (R-squared = 2.39E-06, p=0.996). The bivariate data regression results are shown in Figure 1 in the form of a scatter-plot. Results for the US bivariate analysis of peak-mortality-rate (PMR) against total mandate days are captured in Figure 2. The correlation of the standardized US peak-mortality-rate with total-mandate-days of social-distancing mandates prior to the peak was found to be statistically insignificant (R-squared = 0.0534 with p-val = 0.2463).

Bivariate Analysis, PMR vs Population Density

Results for the bivariate analysis of peak-mortality-rate against US state average population density are captured in Figure 3. The correlation of the standardized peak-mortality-rate with total-mandate-days of social-distancing mandates prior to the peak was found to be statistically significant (R-squared = 0.3814 with p-val = 0.0006). The bivariate analysis was repeated with respect to European population density. The slope of the standardized mortality per European country correlated to the population density and was statistically significant (R^2 = 0.358 with p=0.0398). The bivariate data regression results are shown in Figure 4 in the form of a scatter-plot.

Table 2 Data on Population Density, Median Age, Social Mandate, and Covid-19 Mortality, and Covid-19 Maximum Mortality Rate on the 12 European Countries Used in This Analysis. Covid-19 Data Was Obtained from IHME and Census Data.[7,9,10]

Country	Peak Daily Death Rate	Date of Peak Daily Death Rate	Mortality at Date of Peak Death Rate	Stay-at-Home Mandate		School Closure Mandate		Non-Essential Business Closure Mandate		Travel Restrictions Mandate		Total Mandate Days	Median Age
	Deaths/Million/Day		Deaths/Million	Start Date	# Days Prior to Peak	Start Date	# Days Prior to Peak	Start Date	# Days Prior to Peak	Start Date	# Days Prior to Peak	Days	Years
Austria	2.34	8-Apr	29.6	16-Mar	23	16-Mar	23	16-Mar	23	N/A	N/A	69	44
Belgium	25.8	12-Apr	303	18-Mar	25	14-Mar	29	18-Mar	25	N/A	N/A	79	41.4
Denmark	2.83	6-Apr	31.7	N/A	N/A	16-Mar	21	N/A	N/A	N/A	N/A	21	42.2
Finland	1.96	22-Apr	25.5	N/A	N/A	18-Mar	35	4-Apr	18	25-Mar	28	81	42.5
France	12.2	5-Apr	152.7	16-Mar	20	12-Mar	24	14-Mar	22	17-Mar	19	85	41.4
Sweden	8.8	22-Apr	89	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	41.3
Switzerland	6.65	5-Apr	81.1	N/A	N/A	13-Mar	23	16-Mar	20	N/A	N/A	43	42.2
UK	13.44	10-Apr	152.6	23-Mar	18	23-Mar	18	20-Mar	21	N/A	N/A	57	40.5
Poland	0.526	1-May	17.6	24-Mar	38	12-Mar	50	N/A	N/A	N/A	N/A	88	41.1
Luxemburg	4.47	10-Apr	91.4	N/A	N/A	16-Mar	25	18-Mar	23	N/A	N/A	48	39.3
Netherlands	8.62	5-Apr	100.6	N/A	N/A	15-Mar	21	N/A	N/A	N/A	N/A	21	42
Portugal	3	12-Apr	48	19-Mar	24	16-Mar	27	19-Feb	53	N/A	N/A	104	43.7

Note: Fields with "N/A" indicate the country did not implement that particular form of social mandate in the timeframe observed in this study.

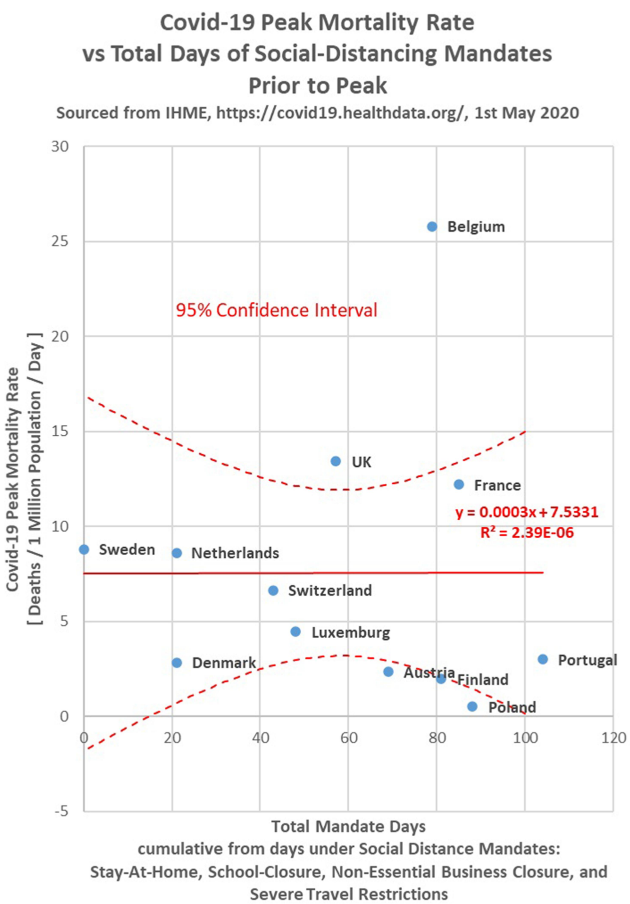

Figure 1 Standardized Covid-19 peak-mortality-rate (PMR) per European country correlated to days under mandated social distancing directives prior to the peak.
Notes: Blue datapoints are labeled with their respective country name. The solid red line denotes a line-of-best-fit. The dotted red curves denote the upper and lower bounds of the 95% confidence interval about the line-of-best-fit.

Bivariate Analysis, MAP vs Population Density

Results for the bivariate analysis of mortality-at-peak against average US state population density were analyzed. The correlation of the mortality-at-peak with average US state population density was found to be statistically significant (R^2 = 0.5238 with p-val = 1.99E-05). Likewise, the standardized mortality at the peak per European country also correlated to the population density and was statistically significant (R-squared = 0.397 with p=0.0281).

Multivariate Analysis on MAP

Results for the US and European multivariate analysis of mortality-at-peak on the date of initial peak-mortality -rate were separately analyzed in the GLME. In each study, one modeled effect was found to be statistically significant at the 5% significance level; this was a state's/country's average population density (p-val = 0.0004, p-val = 0.0046).

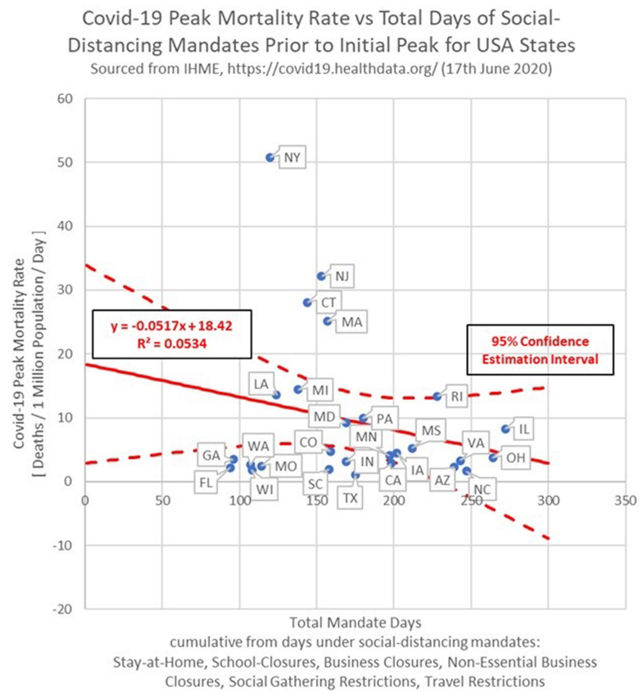

Figure 2 Standardized Covid-19 peak-mortality-rate (PMR) correlated to days under US state-mandated social distancing directives prior to the peak.
Notes: Blue datapoints are labeled with their respective state abbreviation. The solid red line denotes a line-of-best-fit. The dotted red curves denote the upper and lower bounds of the 95% confidence interval about the line-of-best-fit.

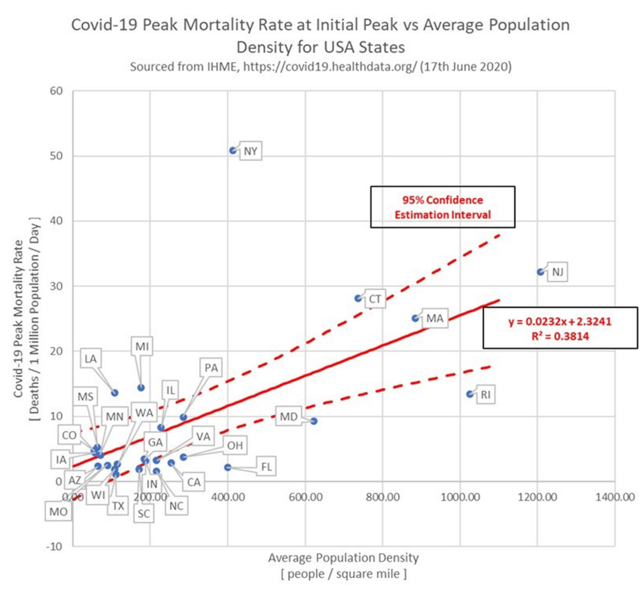

Figure 3 Standardized Covid-19 peak-mortality-rate (PMR) correlated to US state average population density.
Notes: Blue datapoints are labeled with their respective state abbreviation. The solid red line denotes a line-of-best-fit. The dotted red curves denote the upper and lower bounds of the 95% confidence interval about the line-of-best-fit.

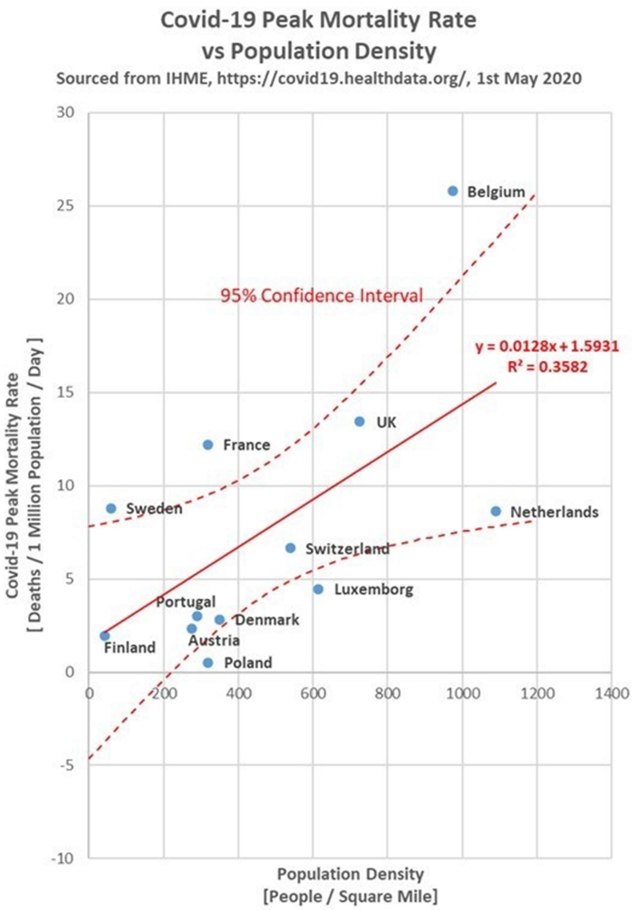

Figure 4 Standardized Covid-19 peak-mortality-rate (PMR) correlated to European country average population density.

Notes: Blue datapoints are labeled with their respective country name. The solid red line denotes a line-of-best-fit. The dotted red curves denote the upper and lower bounds of the 95% confidence interval about the line-of-best-fit.

Multivariate Analysis on PMR

Results for the US and European multivariate analysis of peak-mortality-rate were captured in the GLME. In each study, One modeled effect was found to be statistically significant at the 5% significance level; this was a state's/country's average population density (p-val = 0.0025, p-val = 0.0042).

The European study also revealed under the multivariate analysis that school closures had an expected effect on the PMR and on the MAP (p-val = 0.0142,0.0265) and the stay-at-home orders actually had a negative effect (increased mortality) on the PMR and MAP (p-val = 0.0303.0.0476). However, the US multivariate analyses did not corroborate these findings with all factors producing statistically insignificant results.

Discussion

The analysis appears to show no statistically significant US reduction in the slope of the Covid-19 mortality rate (p-val = 0.995) nor in Covid-19 mortality (p-val = 0.246) to its defined initial mortality peak. Likewise, the analysis appears to show no statistically significant European reduction by combined mandated-days in either the slope of the Covid-19 mortality rate (p-val = 0.996) nor in Covid-19 mortality (p-val = 0.854) to its defined initial mortality peak. There was a significant correlation to both the overall mortality and the maximum mortality rate to population density in both the US and Europe. The correlation to population density suggests that the proximity and frequency of social interactions directly affect the mortality rate and overall mortality. However, the evaluation of statutory mandates suggests that they were unable to reduce the frequency of social interactions to be effective. The results separately analyzed in the US and Europe corroborate each other conducted using the same methodology with the IHME data.[8]

One of the advantages in this analytical approach is in the design of the social-mandate input variables to be more robust to possible biases caused by different states being in different epidemiologic infectious stages of Covid-19. It is worth noting that most of the states and countries included in this study have since experience a second wave of infections not included in this analysis. This may be a successive superposition of infectious cycles within the state in sequestered populations or an effect of behavioral changes within the population. Only their initial peaks were the subject of this study and they were not revised to the new peak nor excluded. Mandates and social behaviors changed substantially during the interim between the first maximum and could confound the analysis. Furthermore, the strong correlation to population density demonstrating a likely effect of personal interaction frequency which assists in validating the methodology. It is also worth noting that start dates of social-mandate implementation does not necessarily imply a certain degree of compliance of the population with enacted mandates.

The length of time before the initial peak a form of social-mandate was implemented by a US state was not found to be statistically significant in its effect on peak-mortality-rate and mortality-at-peak in both the US bivariate studies and the multivariate studies. The lowest associated p-value with social-mandate terms across all studies above was p-val > 0.2463 in the bivariate study of studying standardized Covid-19 peak-mortality-rate against total-mandate-days. However, the average population density was found to be a statistically significant factor for both peak-mortality-rate and mortality-at-peak of a state in both the bivariate and multivariate studies. The largest associated p-value with average population density across all studies above was p-val = 0.0025 in the multivariate study with peak-mortality-rate. The results were corroborated by the European study analyses with the exception of the multivariate analyses demonstrating a positive effect due to school closures and a negative effect due to stay-at-home orders.

The primary finding is that the timing and scope of social-mandates alone is not enough to explain the variability in Covid-19 peak-mortality-rate and mortality-at-peak numbers between states or countries. However, a state's average population density is a significant factor and should be accounted for in one way or another in current and future investigations to explain the variability in Covid-19 peak-mortality-rate and mortality-at-peak numbers between states.

Factors which influence the effectiveness of social distancing interventions include the reproduction number (R_0) of the virus, the mortality rate, and the mandate effectiveness of the isolation.[12,13] A reduction of the slope of the maximum mortality rate without a change in total mortality is consistent with theory of viral infectious epidemiology.[14] Reductions in total mortality due to reduced healthcare system or advancements in medical care did not materialize in this analysis. However, the time from the probable first registered death to the peak of the mortality rate was only 3 months. It is possible that if the viral mortality estimated at 0.6% to 1.2% or the viral reproduction R_0, estimated between 2.8 and 3.3, were significantly higher may have produced a correlation.[11,12] Mandated interventions which were significantly more isolating also may have produced a correlation to the mortality. A longitudinal study has found reduced mortality associated with social distancing intervention.[15] However, the absence of demonstrable social distancing effect on infectious case rates have been supported in recent a observational study, Bendavid et al.[16]

The analysis is presented as a potential methodology to evaluate the effectiveness of statutory social distancing policy. Western European countries and US states were selected for this study due to their respective cultural and healthcare similarities. A possible future study would be to conduct a similar analysis on other clusters of countries with cultural similarities and interventional policy variations.

Abbreviations

FDA, Food and Drug Administration; CFR, Code of Federal Regulations; IHME, Institute of Health Metrics and Evaluation; GLME, General Linear Mixed-Effects; PMR, Peak-mortality-rate due to Covid-19 as calculated using Equation 1; MAP, Mortality-at-peak due to Covid-19, standardized by state total population as reported in referenced IHME data.

Data Sharing Statement

Depersonalized data made available for download on IHME Websites can be used, shared, modified or built upon by non-commercial users via the Creative Commons Attribution-NonCommercial 4.0 International License. https://creativecommons.org/licenses/by-nc/4.0/ Data available Institute for Health Metrics and Evaluation (IHME) http://www.healthdata.org/covid accessed on June 17, 2020 and July 19, 2020.

Preprint version published: Medrxiv 2020; DOI: 10.1101/2020.08.26.20182758.

Ethics Approval and Consent to Participate

This clinical study was conducted in accordance with the ethical principles contained within Declaration of Helsinki, Protection of Human Volunteers (21 CFR 50), Institutional Review Boards (21 CFR 56), and Obligations of Clinical Investigators (21 CFR 812). No IRB was required with the use of depersonalized public data.

Consent for Publication

Not Applicable. Depersonalized data made available for download on IHME Websites can be used, shared, modified or built upon by non-commercial users via the Creative Commons Attribution-NonCommercial 4.0 International License. https://creativecommons.org/licenses/by-nc/4.0/

Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

Funding

This study was not funded.

Disclosure

The authors report no conflicts of interest in this work.

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