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COVID-19: Mathematical estimation of delay to deaths in relation to upsurges in positive rates

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ABSTRACT

Introduction: The world continues in the grip of the COVID-19 pandemic. Widespread public health measures and travel restrictions have dampened viral spread but outbreaks are expected as restrictions are raised. This study was carried out in order to devise an approach that may help to predict deaths based on upsurges (spikes or waves) of cases.

Methods: Publically available data for daily new cases and deaths from December 2019 to August 2020 was obtained from the *Our World In Data* website. For the purposes of more detailed analysis, in addition to total global data, three countries were chosen for sub analysis: Italy, Germany and the United States.

Results: Delay to death (days) were as follows: World: 20.6 (95% CI: 8.4–32.8); USA: 19.8 (95% CI: 9.3–30.4); Germany: 18.8 (95% CI: 6.1–31.6); Italy: 2.4 (95% CI −10.2–15.0).

Discussion: Countries may be able to contain viral resurgence by adhering to WHO advice for reopening from restrictions/lockdowns. However, outbreaks are almost inevitable and deaths are to be expected approximately 20 days after rises in cases. This paper may therefore aid healthcare systems and hospitals for surges in cases as positive COVID-19 swabs increase in any given locality. Italy was an exception in these results as the initial surge and swabs taken represented symptomatic/admitted cases and not community surveillance tracking and tracing.

1. Introduction

The world is stricken by the COVID-19 pandemic that was initially identified in Wuhan, China, in December 2019, a virus that circulates widely before resulting in severe infections that produce hospital admissions and deaths [1,2]. COVID-19 precipitated international travel bans in March 2020 so as to slow down and dampen viral spread, and this affected over 90% of the world's population [3]. This, accompanied by public health measures, may have delayed millions of infections and prevented the deaths of millions more [4,5].

While COVID-19 is a beta coronavirus and not an influenza virus, its transmission characteristics are similar to influenza and it is expected to resurge after being dampened in a series of waves as restrictions are relaxed and reapplied [6]. These successive wave/s have length/s and amplitude/s that are determined by herd immunity and the stringency of applied lockdowns [7].

This paper will utilise publicly available national datasets of COVID-19 detections by swabbing, and deaths in order to attempt to devise an approach that may help to predict deaths based on upsurges (spikes or waves) of cases.

2. Methods

Publically available data for daily new cases and deaths from December 2019 to August 2020 was obtained from the *Our World In Data* website [8]. Data is available for swab confirmed cases and this is an inherent limitation in any such study as:

1. It is estimated that there are many asymptomatic or mild cases that are undocumented [9].

Table 1
Overview of deaths, positive cases, swab tests, and swab positive rates.

Period	Germany[a]	Italy[a]	United States[a]	World[a]
Deaths				
March	583	11,570	3170	7333
April	5705	16,091	57,796	124,493
May	2212	5658	42,815	109,042
June	473	1404	22,359	97,449
July	168	388	25,930	137,553
Total	**9141**	**35,111**	**152,070**	**475,870**
Cases				
March	61,856	./.	164,554	350,706
April	97,206	10,597	875,289	1,843,032
May	22,363	29,073	730,475	2,258,043
June	12,777	7772	820,168	3,064,620
July	14,439	6722	1,904,462	5,898,263
Total	**208,641**	**54,164**	**4,494,948**	**13,414,664**
Tests				
March	734,190	./.	764,389	3,438,980
April	1,577,526	210,488	4,870,381	19,212,119
May	1,703,965	1,082,124	10,170,000	41,327,978
June	1,631,450	862,743	14,650,000	54,309,570
July	2,350,401	783,358	22,570,000	75,833,940
Total	**7,997,532**	**2,938,713**	**53,024,770**	**194,122,587**
Positive rate (%)				
March	8.43	./.	21.53	10.20
April	6.16	5.03	17.97	9.59
May	1.31	2.69	7.18	5.46
June	0.78	0.90	5.60	5.64
July	0.61	0.86	8.44	7.78
Total	**2.61**	**1.84**	**8.48**	**6.91**

[a] World: countries and periods with known numbers of tests ('new_tests_smoothed' > 0).

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Table 2
Standardized cross-correlation functions (CCF) for point and 95% confidence interval estimation of the delay of daily deaths in relation to daily positive rates.

World[a]		United States		Germany		Italy	
Lag	Standardized CCF	Lag	Standardized CCF	Lag	Standardized CCF	Lag	Standardized CCF
−4	0.41	-4	−1.03	−4	2.37	−24	0.09
−3	1.27	−3	−0.37	−3	3.12	−23	0.12
−2	1.99	−2	0.37	−2	4.10	−22	0.60
−1	2.64	−1	1.08	−1	4.83	−21	0.82
0	3.16	0	1.26	0	5.30	−20	0.78
1	3.21	1	1.87	1	4.98	−19	1.07
2	3.25	2	1.75	2	5.01	−18	1.24
3	3.83	3	2.25	3	5.51	−17	2.04
4	4.69	4	2.79	4	6.36	−16	1.91
5	5.56	5	3.61	5	7.31	−15	2.42
6	6.30	6	4.66	6	8.00	−14	2.92
7	6.60	7	4.93	7	8.13	−13	3.22
8	6.46	8	5.44	8	7.99	−12	3.62
9	6.33	9	5.67	9	7.61	−11	4.10
10	6.65	10	5.84	10	7.84	−10	4.58
11	7.43	11	6.37	11	8.76	−9	4.72
12	8.09	12	7.32	12	9.64	−8	5.24
13	8.70	13	7.74	13	9.92	−7	5.90
14	8.60	14	8.42	14	9.72	−6	6.60
15	8.62	15	8.52	15	9.26	−5	6.86
16	8.41	16	8.44	16	8.90	−4	7.24
17	8.55	17	8.40	17	8.84	−3	7.40
18	8.67	18	8.62	18	9.64	−2	7.83
19	9.30	19	9.08	19	10.40	−1	8.55
20	9.40	20	9.50	20	10.52	0	9.19
21	9.25	21	9.37	21	9.92	1	8.46
22	8.46	22	9.06	22	8.85	2	8.34
23	8.27	23	8.31	23	8.16	3	8.01
24	8.00	24	8.12	24	8.16	4	7.65
25	8.28	25	7.87	25	8.69	5	7.37
26	8.40	26	8.03	26	9.21	6	7.38
27	8.54	27	7.85	27	8.94	7	7.24
28	7.86	28	7.68	28	8.26	8	6.27
29	7.20	29	6.85	29	7.40	9	5.92
30	6.37	30	6.04	30	6.36	10	5.86
31	6.15	31	4.72	31	6.06	11	5.81
32	6.04	32	4.73	32	6.57	12	5.28
33	6.22	33	4.65	33	6.80	13	5.15
34	5.99	34	4.36	34	6.46	14	4.73
35	5.64	35	3.57	35	5.94	15	4.45
36	4.82	36	2.88	36	5.08	16	4.12
37	4.16	37	1.69	37	4.18	17	3.94
38	3.77	38	1.18	38	3.93	18	3.83
39	3.97	39	0.87	39	4.17	19	3.72
40	4.09	40	0.88	40	4.41	20	3.34
41	4.08	41	0.67	41	4.21	21	2.93
42	3.45	42	0.47	42	3.90	22	2.61
43	2.69	43	−0.11	43	2.91	23	2.46
44	1.91	44	−0.62	44	2.11	24	2.36

[a] World: countries with known number of tests.

2. Some cases may never be documented even if death ensues due to the absence of sufficient testing capacity as is common in developing countries (and even some developed countries such as the United States) [10].

For the purposes of this analysis, only countries with information on the counts of daily Covid-19 tests performed were included (fields in the dataset labelled *'new_tests or new_tests_smoothed > 0'*). Of the 211 countries available in the dataset, 92 countries performed 217,843,283 tests. This subset of 92 countries represents 512,601 daily deaths (70.1% of total World) and 15,109,179 daily cases (76.1% of total World). For the estimation of the optimum time delay, data was further restricted to the period February 1 to August 1, 2020 to avoid boundary effects due to small, incomplete, or more recent and still instable counts.

The cross-correlation function (CCF) of signals is a time series analyses tool. Parabola functions are commonly used as parametric models of the CCF in time delay for point and 95% confidence interval estimations [11]. The optimum time delay was defined as the time lag between daily deaths and the daily positive rate yielding the maximum of the standardized cross correlation function. For a single parameter, the 2 points that lie 1.96 units away from the maximum of the standardized cross correlation function provide 95% confidence intervals for the overall time delay between the two time series compared. Data smoothing was achieved by a centred 7-day average of daily data. Data was processed with MS-Excel-365 (2016), R 3.5.1, Wolfram MATHEMATICA 11.3, and mostly SAS/STAT software 9.4, namely SAS-PROCs CORR, SQL, and TIMESERIES (SAS Institute Inc.: SAS/STAT User's Guide, Cary NC: SAS Institute Inc., 2014).

For the purposes of more detailed analysis, in addition to total global data, three countries were chosen for sub analysis. These were Italy due to this country being the first disease epicentre outside of China, and Germany and the United States as two countries that represent effective and ineffective population disease control

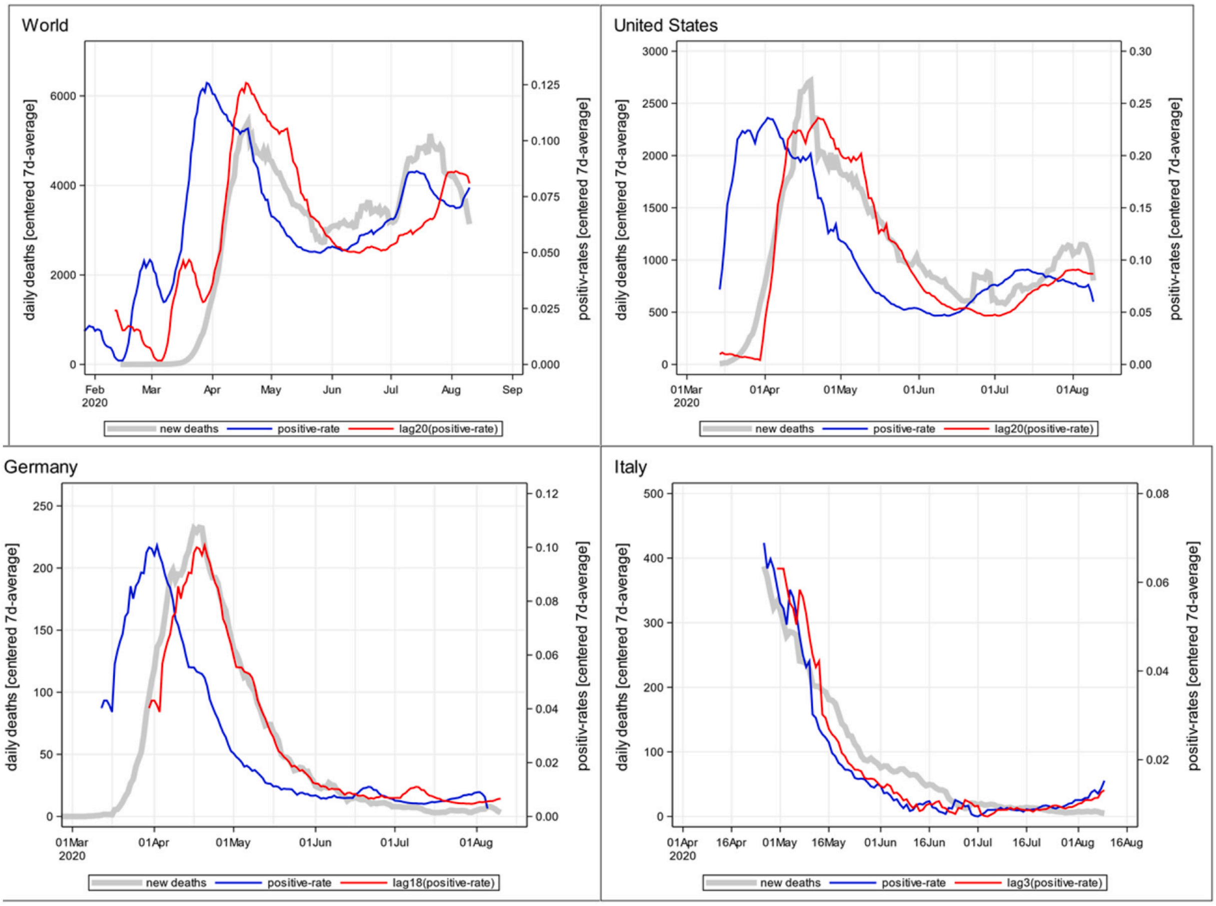

Fig. 1. World (combined countries with information on numbers of tests), United States, Germany and Italy - time series of daily deaths and daily cases.

respectively.

3. Results

For the period 1st January 1 to 10th August 2020, the data shows 731,263 worldwide daily deaths and 19,845,092 Covid-19 cases (symptomatic and asymptomatic).

Counts of daily deaths, cases, Covid-19 tests performed, as well as the corresponding positive rate are shown in Table 1. The standardized cross correlation employed for point and 95%-confidence interval estimation of the optimum time delay between the daily deaths and the daily positive rate are shown in Table 2. Fig. 1 displays the data analysed, and Fig. 2 presents the corresponding time series analyses (optimum time delay estimation) for World, United States, Germany, and Italy, respectively. Delay to death (days) were:

World: 20.6 (95% CI: 8.4–32.8),
USA: 19.8 (95% CI: 9.3–30.4),
Germany: 18.8 (95% CI: 6.1–31.6),
Italy: 2.4 (95% CI −10.2–15.0).

4. Discussion

The world is in the second wave of COVID-19 and in the absence of an effective vaccine and/or effective treatment, resurgences are expected to further take tolls on COVID-19 morbidity, mortality and affected countries' economies [12].

Overall, it appears that spikes or upsurges in cases are followed by deaths approximately 20 days later. The Italian data may be exceptional as Italy was the initial epicentre outside of China and when cases surged, swab positive cases initially represented cases surging into hospitals and not community surveillance with track and trace public health measures. Countries may be able to contain viral resurgence by adhering to WHO advice for reopening from restrictions/lockdowns [13]:

1. Evidence shows COVID-19 transmission is controlled;
2. Public health and health system capacities are in place to identify, isolate, test, trace contacts and quarantine them;
3. Outbreak risks are minimized in high-vulnerability settings, particularly in homes for older people, mental health facilities and crowded places of residence;
4. Workplace preventive measures are established, including physical distancing, handwashing facilities and respiratory etiquette;
5. Importation risks can be managed; and
6. Communities have a voice and are aware, engaged and participating in the transition.

However, despite adequate measures and precautions, cases may still unexpectedly rise. Such sudden and unexpected increases in cases may quickly overwhelm hospitals and healthcare systems [14]. Whatever precautions are taken, spikes are bound to occur and as witnessed in the first wave in Italy and New York, surges may simply overwhelm medical systems capacities to cope [15,16]. and this research may help to prepare hospitals for surges in cases as positive COVID-19 swabs increase in any given locality.

Declaration of competing interest

The authors have no conflict of interest to declare.

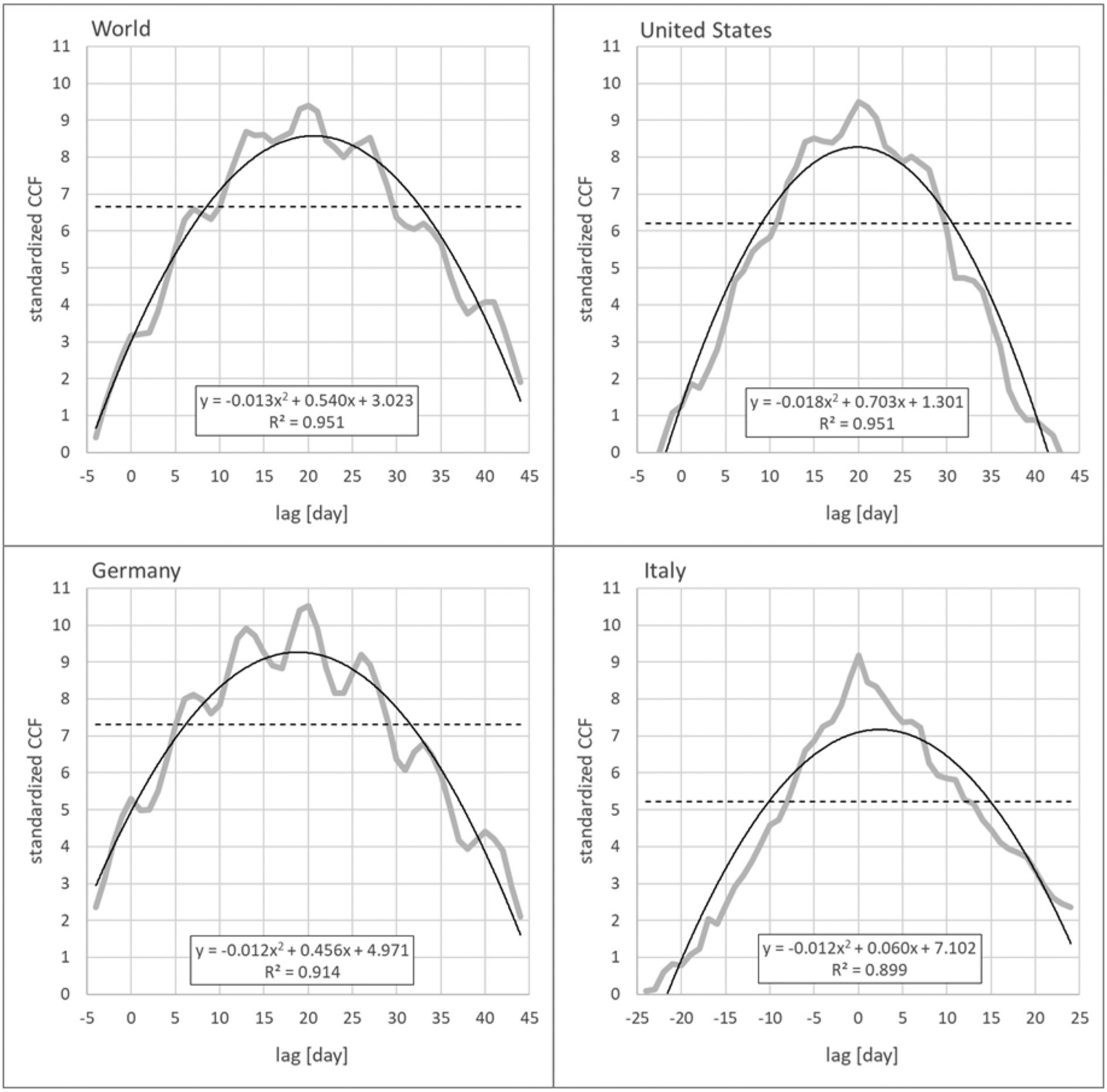

Fig. 2. World (combined countries with information on numbers of tests), United States, Germany and Italy - standardized cross-correlation function (CCF, gray) and fit-parabola (black, solid) for daily deaths and lag_{20} (positive rate); intersections of the fit-parabola with horizontal.

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