Article

All-cause Excess Mortality and Confirmed COVID-19 Deaths in Italy: A Peak Comparison Analysis

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Abstract: During a sanitary crisis, excess mortality measures the number of all-cause deaths, beyond what we would have expected if that crisis had not occurred. The high number of COVID-19 deaths started a debate in Italy with two opposite positions: those convinced that COVID-19 deaths were not, by default, excess deaths, because many COVID-19 deaths were not correctly registered, with the most part attributable to other causes and to the overall crisis conditions, and those who presented the opposite hypothesis. We analyzed the curve of the all-cause excess mortality, during the period January 5, 2020 – August 28, 2022, compared to the curve of the daily confirmed COVID-19 deaths, investigating the association between excess mortality and the recurrence of COVID-19 waves in Italy. We compared the two curves looking for the corresponding highest peaks and we found that 5 out of the 6 highest peaks (83.3%) of the excess mortality curve have occurred, on average, just a week before the concomitant COVID-19 waves hit their highest peaks of daily deaths (Mean 6.4 days; SD 2.4 days). This temporal correspondence between the moments when the excess mortality peaked and the highest peaks of the COVID-19 deaths provides further evidence that the all-cause excess mortality wave has been mostly driven by COVID-19 deaths.

Keywords: COVID-19; pandemic; Italy; daily confirmed deaths; all-cause excess mortality; peak comparison; public health; epidemiology; health informatics

1. Introduction

After almost 3 years from the beginning of the COVID-19 pandemic, the scientific community is still discussing about many of the characteristics of this disease, including its most serious implications, like deaths, unfortunately. People in fact are still dying of COVID-19 all around the world, with an estimated cumulative number of confirmed deaths that hit almost 6.6 million, as of November 20, 2022 [1].

The World Health Organization (WHO) has proposed the following definition for deaths due to COVID-19 [2]: "A death due to COVID-19 is defined as a death resulting from a clinically compatible illness, in a probable or confirmed COVID-19 case, unless there is a clear alternative cause of death that cannot be related to COVID disease. There should be no period of complete recovery from COVID-19 between illness and death" and "A death due to COVID-19 may not be attributed to another disease (e.g., cancer) and should be counted independently of preexisting conditions that are suspected of triggering a severe course of COVID-19".

Against this apparently unquestionable classification, a dispute has ignited over what a COVID-19 death is, with many arguing that whether one died of COVID-19 or with COVID-19 is open to interpretation [3]. Two opposite positions emerged quite clearly: on one side, those who believe that this high number of COVID-19 deaths was an overestimate of the actual mortality from the disease, maintaining that COVID-19 did not actually cause many of the deaths for which medical authorities held it responsible, essentially because those recorded deaths had erroneously COVID-19 as the main underlying cause of death, rather than a contributing cause [4-6]. Others, on the opposite side, instead, think that the world has paid to COVID-19 a death toll which is even larger than that the official figures show, particularly in the early months of the pandemic and in

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low- and middle- income countries, claiming that, due to limited registrations and problems in the attribution of the cause of death, many deaths went unrecorded or not correctly diagnosed as of COVID-19 [7, 8].

In epidemiology and public health, the term "all-cause excess mortality" indicates that one compares the all-cause mortality figure of a given period with a value for a similar period, averaged over several previous years. Hence, one way science has used to provide a solution to the problem of an accurate estimate of COVID-19 deaths has been to look at the all-cause excess deaths during the pandemic and compare these to how many people had COVID-19 on their death records. The intent was to verify whether (a part of) these excess deaths can be attributed to coronavirus or not. Unfortunately, also this method has problems as counting excess deaths does not take into account changes in the age of populations. With a population which is getting older, counting excess deaths might give a biased perspective, as some of those deaths would have occurred independently of the pandemic because of the age of some portions of that population. Not only that. During a pandemic, deaths from some causes could have decreased, like those from other infectious diseases due to the positive effect of lockdowns, while others could have increased because of the overall crisis conditions, thus affecting this excess death figure.

Nonetheless, a vast amount of recent research has followed this excess mortality approach to provide a solution to the problem of an accurate estimate of COVID-19 deaths, leading to results of various type, almost all converging towards the hypothesis of a positive correlation between the number of actual COVID-19 deaths and the all-cause excess mortality rate. Among many others, remarkable are the studies conducted in [9-11]. In [9], Vestergaard *et al*. studied European-wide weekly mortality estimates, from several European countries in the period from the beginning of 2020 until the beginning of May 2020, using an age-stratified method. Comparing the excess mortality of this short period with the cumulative excess all-cause mortality of the same period of the previous 4 years (2016-2019), they found that the estimated excess mortality could primarily be attributed to COVID-19 and its implications. In [10], instead, Dorrucci *et al.* compared all-cause excess mortality between the two waves that occurred during the year 2020 in Italy using nationwide data and concluding that males and those aged 80 or over were the most hit groups, with an increase in both during the second wave of the pandemic. Finally, in [11] Wang *et al.* developed a huge and more complete study, with excess mortality rates from 74 countries and an emsemble of various statistical models to conclude that, although reported COVID-19 deaths between January 1, 2020, and December 31, 2021, totaled 5.94 million worldwide, their estimate amounted to 18,2 million people died because of the COVID-19 pandemic over that period. This study, nonetheless, emphasizes the fact that although the excess mortality rate is a good predictor for the COVID-19 death rate, it is likely it also includes people died due to other causes due to this planetary crisis.

If we move to Italy, we cannot omit to say that official data (i.e., WHO) says that Italy has paid a death toll of circa 180.518 people, as of November 20, 2022 [12] which is impressive if proportioned to the total Italian population. Moreover, the Italian Institute of Statistics (ISTAT) has recorded a total number of deaths for all causes in Italy in 2020 equal to 746.146, with an all-cause excess mortality as large as 100.526, estimated based on a comparison with the average from the years from 2015 to 2019. This estimate leads to a percentage difference between the reported number of deaths in 2020 and the projected number of deaths for a similar period from previous years equal to 15.6% [13]. Analogous computations and estimates were conducted by ISTAT also for year 2021. The relative figures say that the deaths for all causes were as many as 709.035 and that the all-cause excess mortality was estimated as large as 63.000 deaths, with respect to the average period of reference (2015-2019), thus yielding a percentage of excess deaths in 2021 of 9.8%. As to year 2022, the process is still on course and no announcement on the final estimates, on a yearly basis, has been given yet. Apart from the official data, the situation of the public debate in Italy on the issue of the under/over-estimate of the actual number of

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COVID-19 deaths is similar to that we have already described before, with the two sides bringing to the table mostly the same arguments discussed above, with occasional country-specific remarks.

Following this scientific debate, we decided to choose another technical perspective in order to investigate the hypothesis of a possible direct association between the actual number of COVID-19 deaths and the all-cause excess mortality rates in Italy (2020-2022), based on the use of techniques from signal processing [14]. In particular, we carried out a peak detection analysis of two different curves: the percentage difference between the number of weekly all-cause deaths and the projected number of deaths for the same period based on previous years (2015-2019) and the daily confirmed death cases (7-day rolling average). We found that almost the totality the highest peaks of the excess mortality curve in Italy have occurred, on average, just a week before the concomitant COVID-19 waves hit their highest peaks of daily deaths. In essence, we found that the all-cause excess death curve has always reached its maximum in coincidence with the peak of the concomitant wave of the COVID-19 deaths, thus providing further evidence that, at least in Italy, the excess mortality was mostly driven by COVID-19 deaths.

2. Materials and Methods

Aiming to avoid the dispute described in the previous Section using the same techniques used so far by the scientific community, we decided to work with the Italian population-wide data relative to deaths, focusing only on the two following temporal data series: i) the excess mortality for all causes, given by the percentage difference between the number of weekly deaths, in the period January 5, 2020 – August 28, 2022 and the estimated number of deaths for the same period based on previous years (2015-2019), and ii) the daily new confirmed COVID-19 deaths (7-day rolling average) in the period February 26, 2020 – November 11, 2022.

As to the first series of data, they are plotted under the form of percentages of all-cause excess mortality in Figure 1, for the period of interest. All the following considerations are in order. First, these data are taken from the dataset of project termed: OurWorldinData.org [16].

Its public repository with all data on excess mortality is available at: https://github.com/owid/covid-19-data/tree/master/public/data/excess_mortality. The excess mortality percentages reported in Figure 1 is calculated by OurWorldinData.org, based on the following well-known formula:

$$\text{Percentage Excess Deaths} = 100 \times (\text{Reported Deaths} - \text{Expected Deaths})/\text{Expected Deaths}, \quad (1)$$

using the reported death data provided by both the Human Mortality Dataset (HMD) and the World Mortality Dataset (WMD) projects [17, 18]. The projections, instead, come from just WMD. In particular, HMD maintains on a weekly basis an updated report on the deaths data, sourced from Eurostat and several national statistical agencies (including the Italian ISTAT) [17]. WMD, instead, is a dataset, currently serving 120 countries, whose contents is used to provide an estimate on the projected deaths of all those countries on a per week basis. Essentially, with deaths data from the period 2015-2019, Karlinsky and Kobak (WMD) have first fit a regression model for each region of interest (including Italy), and then use the model to project the expected deaths during the various weeks of the period 2020-2022 [18]. Then, WMD's projected deaths are used by the OurWorldinData.org project as a baseline for estimating the Expected Deaths in the Formula 1 above. At that point of this long process, OurWorldinData.org is ready to provide the temporal series of data like those plotted in Figure 1 for Italy [19].

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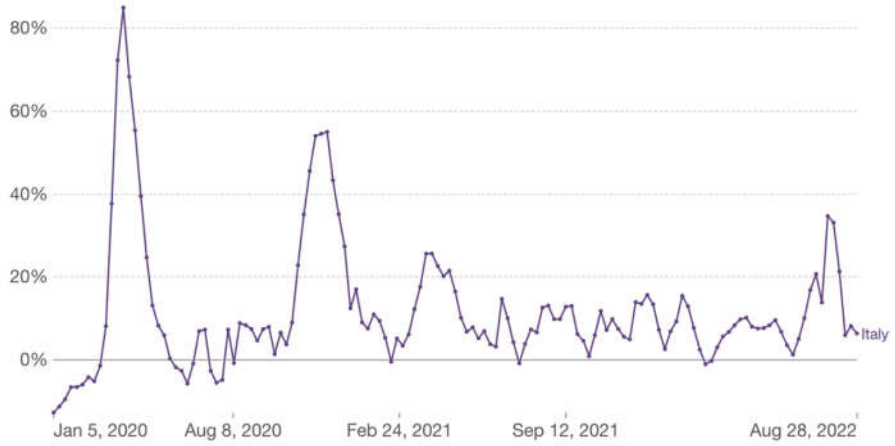

Figure 1. Excess mortality for all causes in Italy: on the y-axis the percentage difference between the number of weekly deaths, in the period January 5, 2020 – August 28, 2022 (x-axis), and the projected number of deaths for the same period based on previous years (2015-2019). Sources: Our World in Data (2022), Human Mortality Database (2022), World Mortality Dataset (2022).

As to the second series of data, Figure 2 plots the number of daily confirmed COVID-19 deaths in Italy in the period 26 February 2020 – 11 November 2022. For each day in the period, the 7-day average rolling is shown, which means that the number of the daily confirmed deaths of the 7 latest days are taken, then they are added up, and finally divided by 7. It is to notice that the complete COVID-19 dataset on daily deaths is maintained again by the OurWorldinData.org projct, with raw data on daily confirmed deaths from 219 countries (including Italy) sourced from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU) [20]. JHU makes them available at the following public repository: https://github.com/owid/covid-19-data/tree/master/public/data/jhu.

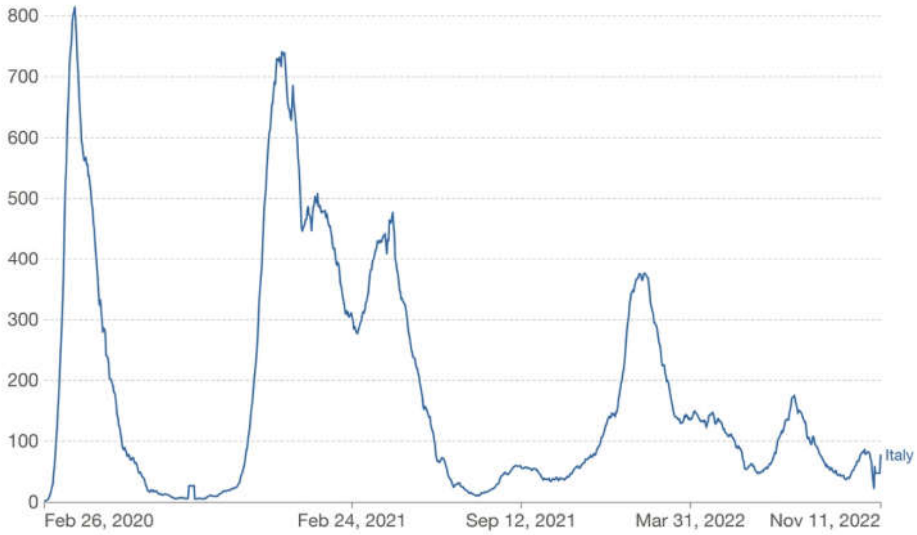

Figure 2. Number of daily confirmed COVID-19 deaths in Italy: on the y-axis the number of new daily COVID-19 deaths (7-day rolling average) in the period 26 February 2020 – 11 November 2022 (x-axis). Sources: Our World in Data (2022), Johns Hopkins University CSSE COVID-19 Data (2022).

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The method we adopted for our investigations was a traditional peak detection analysis conducted on both the curves plotted in Figures 1 and 2. This is a common technique able to find the peaks in an incoming signal and borrowed from fields like electrical signals, digital audio and seismic waves [15]. The basic algorithm is a great fit when the peaks significantly emerge in comparison to the background data. Its easiest application is when we are looking for just the highest spike. In that case, we simply look at each point in the data series and record the highest one seen so far. When the end of the data series is reached, the highest recorded value is the highest peak we were looking for. Obviously, this simple procedure is only able to find the highest peak in a series. If we are looking for multiple peaks in the same data series, instead, we need to add some simple modifications to the basic procedure described before.

To this aim, based on recent literature on peak detection applied to the analysis of COVID-19 waves [21], we have added to the basic procedure the following modifications. As to the curve plotted in Figure 2 (i.e., daily confirmed deaths), two additional conditions were added that need to be satisfied for a point in the curve to be considered one of the highest peaks. First, we can say that a point in the curve corresponding to a given day (say n) of the daily confirmed deaths can be considered a potential peak if the 7-day rolling average number of the daily confirmed deaths computed in that day is larger than the 7-day rolling average number of daily confirmed deaths reported in all the 28 days both before and after n. Not only, but to consider that point in the curve as one of the highest peaks, the 7-day rolling average number of registered deaths on that day n has to be larger than a given threshold computed as the 85% of the cumulative number of deaths reported on day n-1, averaged over all the days since the beginning of the pandemic until n-1. Obviously, there is a rationale behind the choice of the two conditions above. First, choosing 28 days with a lower value of daily confirmed deaths comes from the working definition of COVID-19 wave as provided in [22], where it is shown that the three quarters of the upward periods before a peak of many studied COVID-19 waves lasted less than a month. Similarly, for the downward periods. Second, the motivation behind the concept of having a baseline (i.e., the 85% of the cumulative number of deaths averaged on all previous n -1 days) comes from the need to filter out all those micro peaks that could emerge from very flattened waves.

Similar conditions need to be valid to make a point in the curve of Figure 1 (i.e., the percentage excess mortality) eligible as a peak. Again, the condition should be satisfied which is relative to the existence of 28 days, both before and after a given day n, each with a value of the percentage excess mortality lower than the value recorded at day n. Second, also in this case a baseline plays a role, with a value of the percentage excess mortality below which a point in the curve cannot be considered a peak. In the specific case of the percentage excess mortality curve in Italy, the baseline value was set equal to 15.6%. The motivation behind the choice of this specific value comes from the already cited analysis of the Italian situation conducted by ISTAT that considered the first year of the pandemic as the worst one from its beginning, with an average (on a yearly basis) of the percentage all-cause excess mortality as large as 15.6% [13]. Needless to say, different countries could decide for different values of the baseline with occasional country-specific considerations.

To conclude this Section, it is to notice that all the data used for our peak detection analysis of the curves plotted in Figures 1 and 2 are those available at the following already mentioned public repositories, in particular for the percentage excess mortality (Figure 1):
https://github.com/owid/covid-19-data/tree/master/public/data/excess_mortality,
while for the curve of the daily confirmed deaths (Figure 2): https://github.com/owid/covid-19-data/tree/master/public/data/jhu.
Moreover, the results of all the peak detection calculations are fully reproducible by using the methods described above. Given the simplicity of the described procedures, these calculation for the peak detections can be conducted with a simple calculator and a spreadsheet to temporarily record the data, without any need to resort computer code.

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3. Results

Figures 3 shows the highest peaks (six) we obtained with our peak detection procedure for multiple peaks when applied to the curve of percentage excess of mortality for all causes in Italy, in the period January 5, 2020 – August 28, 2022. All the computed peaks of the curve satisfy the two conditions discussed in the previous Section and are marked in Figure 3 with red boxes. They are considered as they had occurred on the last day of the corresponding week, as the excess mortality rates are given on a per week basis. The six detected peaks happen on the following dates: March 29, 2020; November 29, 2020; April 4, 2021; December 19, 2021; January 30, 2022, July 24, 2022. They all have 28 days with lower values of the percentage excess of mortality both before and after the days of the peaks. Moreover, they are all above the fixed baseline set at the value of 15.6% [13]. With regard to this last point, it is worth noticing that on June 27, 2021, marked with a yellow box in Figure 3, a relative maximum was found (percentage of excess mortality = 15.6%) which was not considered as one of the highest peaks of the curve as the relative value of the percentage of the excess mortality did not surpass the adopted baseline.

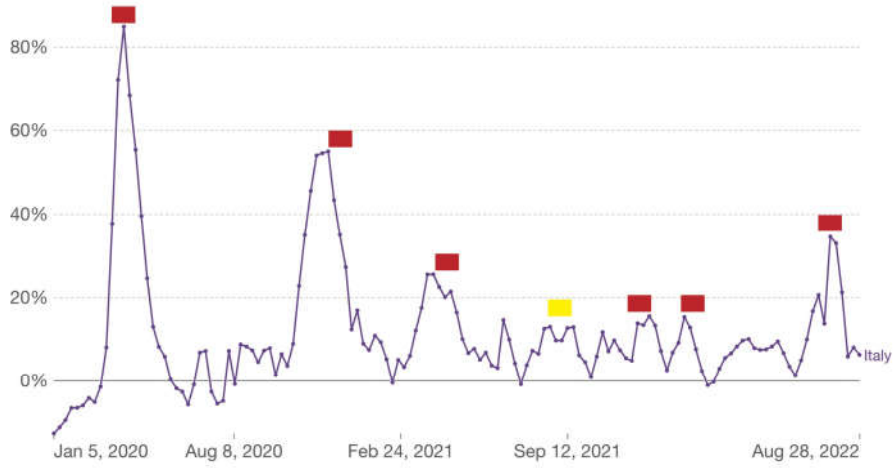

Figure 3. Plot of the peaks for the curve of excess mortality in Italy: on the y-axis the percentage difference between the number of weekly deaths, in the period January 5, 2020 – August 28, 2022 (x-axis), and the projected number of deaths for the same period based on previous years. All the computed peaks of the curve are marked with red boxes and are considered to have occurred on the last day of the corresponding week (precisely on: March 29, 2020; November 29, 2020; April 4, 2021; December 19, 2021; January 30, 2022, July 24, 2022). On June 27, 2021, marked with a yellow box in the plot, a relative maximum is plotted (percentage difference = 15,6%) which did not surpass the baseline.

Figures 4 shows, instead, the highest peaks (five) we obtained with our peak detection procedure for multiple peaks when applied to the curve of the daily confirmed COVID-19 deaths in Italy, in the period January 5, 2020 – August 28, 2022. All the computed peaks of the curve satisfy the two conditions discussed in the previous Section and are marked in Figure 4 with red boxes. The five detected peaks precisely happen on the following dates: April 1, 2020; December 6, 2020; April 13, 2021; February 4, 2022; August 1, 2022. They all have 28 days, with lower values of the 7-day rolling average of the daily confirmed COVID-19 deaths, both before and after the day of the peak. Moreover, they are all above the value of the mobile baseline, set at different values depending on the specific date of the peak, as explained in the previous Section. Also in this case, it is worth noticing that on September 5, 2021, marked with a yellow box in Figure 4, a relative maximum was found (7-day rolling average of the daily confirmed COVID-19 deaths = 60) which was not considered as one of the highest peaks of the curve as the relative

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value of the percentage of the excess mortality did not surpass that of the adopted baseline for that date.

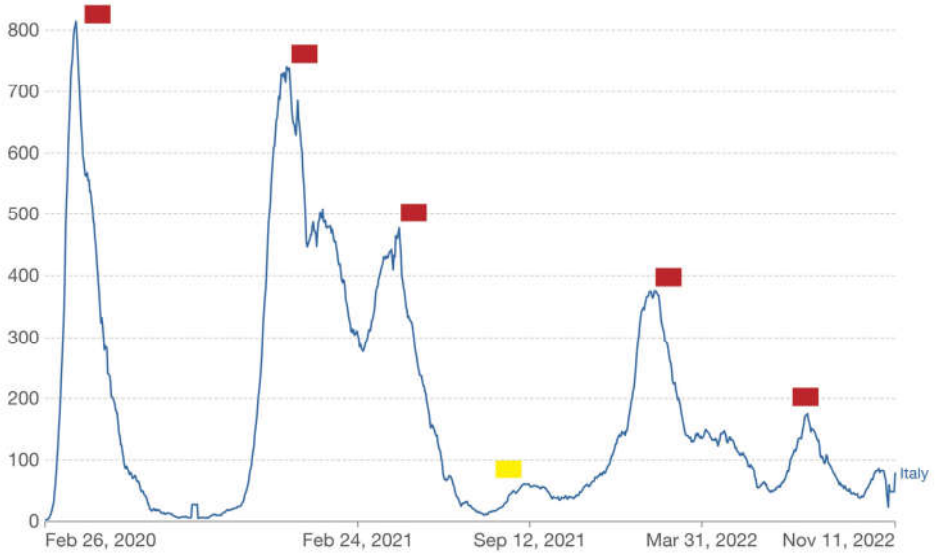

Figure 4. Plot of peaks of the curve of the daily confirmed COVID-19 deaths in Italy: on the y-axis the number of new daily COVID-19 deaths (7-day rolling average), in the period 26 February 2020 – 11 November 2022 (x-axis). All peaks of the curve are marked with red squares (precisely: April 1, 2020; December 6, 2020; April 13, 2021; February 4, 2022; August 1, 2022). On September 5, 2021, marked with a yellow square, a relative maximum was found (7-day rolling average = 60) which could not be considered a peak of the curve as it did not surpass the baseline computed for that date.

For the sake of a clear representation all these results, they have been also reported in Table 1 in their numerical format.

In particular, in the first row of Table 1, we report the dates of the last day of the week when the curve of the percentage excess mortality peaked, along with their percentage values

In the second row of Table 1, for the peaks of the daily confirmed COVID-19 deaths, we report the dates of the peaks with their relative number of deaths (7-day rolling averages), plus the values of the corresponding baseline computed per those dates, based on the rule mentioned in the previous Section.

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Table 1. Peaks of the curves of percentage excess mortality and of daily COVID-19 deaths in Italy. For the peaks of the excess mortality, we report the dates of the last day of the week when the curve of the percentage excess mortality peaked along with their percentage values. For the peaks of the daily confirmed COVID-19 deaths, we report the dates of the peaks, their relative number of deaths (7-day rolling averages) and finally the values (in number of deaths) of the mobile baseline.

Peak	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6
Excess Mortality: last day of the week with the highest peak; corresponding value of % excess mortality.	March 29, 2020 85.6%	November 29, 2020 55.7%	April 4, 2021 26.2%	December 19, 2021 16.2%	January 30, 2022 16%	July 24, 2022 35.5%
COVID-19 Deaths: date of the peak; corresponding 7-day rolling average of deaths, baseline in number of deaths.	April 1, 2020 807 302	December 6, 2020 739 179	April 13, 2021 477 236	Not Appl. Not Appl. Not Appl.	February 4, 2022 376 177	August 1, 2022 175 167

At this point, if we compare the dates of the peaks of the percentage excess mortality curve with those of the daily confirmed COVID-19 deaths, we find that 5 out of the 6 highest peaks (83.3%) of the percentage excess mortality curve have occurred, on average, circa a week before the concomitant COVID-19 waves hit their highest peaks of daily confirmed deaths. In particular, Peak 1 of the daily confirmed COVID-19 deaths occurred 3 days after the corresponding Peak 1 of the percentage excess mortality; Peak 2 of the daily confirmed COVID-19 deaths occurred 7 days after the corresponding Peak 2 of the percentage excess mortality; Peak 3 of the daily confirmed COVID-19 deaths occurred 9 days after the corresponding Peak 3 of the percentage excess mortality; Peak 5 of the daily confirmed COVID-19 deaths occurred 5 days after the corresponding Peak 5 of the percentage excess mortality; Peak 6 of the daily confirmed COVID-19 deaths occurred 8 days after the corresponding Peak 6 of the percentage excess mortality. Finally, yielding a mean value of 6.4 days, with a standard deviation as large as 2.4.

Of the six highest peaks of the percentage excess mortality curve, only one (on December 19, 2021) breaks the pattern (there is no correspondence with any peak in the curve of the daily COVID-19 confirmed deaths). Nonetheless, it is likely that this single peak that does not follow the pattern may tell us something more about the dynamic of the contagion in that specific period of the year in Italy. In fact, that was the period (end of 2021 – beginning of 2022) when the Omicron variant have begun to take over in Italy, becoming seroprevalent very fast. If we look at the shape of the slopes for the curve of the percentage excess mortality in that temporal interval, we notice a very anomalous situation, with two relative peaks quite close each other in time (December 19 vs January 30), both of the same magnitude (16.2% vs 16%), and with a kind of steep canyon in the middle of the two and an excess mortality almost falling to a percentage of 0%. This situation resembles all the characteristics of an outlier, caused by the advent of that variant (i.e., Omicron) that changed the course of the contagion in Italy.

In Tables 2 and 3, we have summarized all these results. In particular, in the first row of Table 2, we show the number of the days, between corresponding pair of peaks of the two curves, while in the first row of Table 3, we report the relative statistics: mean value and standard deviation, measured in days.

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Table 2. Number of days between corresponding pair peaks of the curves of the percentage excess mortality and of the daily COVID-19 deaths in Italy.

Peak	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6
Number of days between corresponding pair of peaks of the two curves	3	7	9	Null	5	8

Table 3. Statistics.

	Mean (days)	Std. Dev. (days)
Statistics relative to the number of days between corresponding pair peaks of the two curves	6.4	2.4

A final consideration is that, if we look at the results shown, respectively, in Figures 3 and 4 and in Tables 1 and 2, we cannot avoid to notice the temporal correspondence between the moments when the percentage excess mortality curve peaked and the highest peaks of the COVID-19 deaths. This suggests that it is very likely that the all-cause excess mortality rate has been fueled by COVID-19 deaths in the examined period in Italy.

4. Discussion

All-cause excess mortality typically refers to the number of deaths from all causes occurred during a sanitary crisis to a larger extent than in normal conditions. Excess mortality has been considered a more appropriate measure of the total impact of the COVID-19 pandemic on deaths than the confirmed COVID-19 death count alone [16]. Nonetheless, the interpretation of the result of the difference between the excess mortality and the amount of confirmed COVID-19 death, in a given period, remains open to discussion.

In fact, if this difference is almost equal to 0, there will be many who would say that this is simply due to the fact that total number of COVID-19 deaths is overestimated as COVID-19 has not actually caused many of the deaths for which authorities held it responsible. Unfortunately, also in the opposite situation (i.e., a value of the difference which is largely positive in a given period), we will find many others who would claim that the number of COVID-19 deaths is underestimated using a symmetric argument, based on the idea that many COVID-19 deaths went unrecorded due to poor testing and diagnosis, especially in low- and middle- income countries.

If we add to this discussion the count of people who died during the pandemic (both COVID-19 and non-COVID-19) due to the overall critical conditions that have often brought the healthcare systems of many countries to their knees, we understand that both the scale of this phenomenon and the limitations of treating it with differences in the data collection process and in the countermeasures taken by different countries have contributed to confounding people and to generating an enormous uncertainty in the scientific debate.

Being conscious that this lack of scientific consensus can be disheartening to people, and that no scientist can deal well with such largely inhomogeneous set of information that the pandemic has generated, in this work we have decided to follow an alternative path in order to investigate the hypothesis of a direct link between excess mortality and COVID-19 deaths, employing a technique from signal processing.

As mortality records are often incomplete and the actual nature of COVID-19 deaths may remain questionable, rather than developing complex statistical models that, at the end, have a hard time to distinguish between the proportion of excess mortality that was directly caused by COVID-19 and the causes of death which were only an indirect con-

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sequence of the pandemic, we resorted to a simpler and more neutral method to investigate the hypothesis of an association between excess mortality and COVID-19 deaths.

Essentially, we identified and counted all the highest peaks in the percentage excess mortality curve in Italy and compared them to the highest peaks of the concomitant COVID-19 waves that have led to their maximum number of confirmed deaths. Our peak detection analysis has showed that the highest peaks of the COVID-19 deaths curve fall, on average, only a week after that the percentage excess mortality curve has hit its maximum values. Certainly, multiple confounding factors may have played a role in the final attribution of many of the COVID-19 deaths, but our opinion is that the temporal coincidence between the moments when the percentage excess mortality peaked and the highest peaks of the COVID-19 deaths curve provides a non-questionable evidence in favor of the hypothesis that all-cause excess mortality has been largely driven by COVID-19 deaths in Italy in the period of our study, with the magnitude of this phenomenon that should be investigated even more thoroughly [23].

Obviously, also our approach has several limitations. First, we recognize that, with our peak detection analysis, we have avoided quantifying the number of deaths precisely attributable to COVID-19. Nonetheless we have followed this approach, deliberately, in order to avoid to being trapped in the never-ending loop circa the correct estimate of the number of COVID-19 deaths in Italy. We took full part in the scientific discussion about the impact that these deaths have had on the all-cause excess mortality, yet we have done this by observing this natural phenomenon from the perspective that a simple mathematical technique, like that of peak detection, may offer, with neutrality and regardless of the underlying discussion on what a COVID-19 death really is [24].

Another limitation of our study is concerned with the limited amount of time during which we have analyzed the percentage all-cause excess mortality curve. From the viewpoint of signal processing techniques, in fact, a period that returns only six peaks could be considered to offer just a limited perspective on the underlying phenomenon. However, one should consider that the period of time we have studied corresponds almost entirely to that of the pandemic. Our analysis has stopped around the end of August, 2022, for the simple reason that the Italian statistical and medical authorities provide data on the excess mortality weekly rates typically with some months of delays. Hence, the latest weekly data on excess mortality being available, at the time of our research, were those relative to the end of August 2002. Moreover, our opinion is that if we were able to analyze the percentage excess mortality rate also in the residual period of September-November 2022, this would add almost nothing to our findings, also considering that in that period in Italy the count of COVID-19 deaths has continued to stabilize in an almost predictable, endemic state (with 70-80 deaths per day, on average), probably due to the high immunity degree achieved by the Italian population, with vaccinations and past infections. Finally, another limitation of the present study resides in the use of Italian data only. The extension to different geographies could obviously result into more robust results and it would allow to discuss our findings and their implications in a broadest a more challenging context.

At the end, with the scientific community that appears divided into two factions, which alternatively claim that the COVID-19 deaths are either underestimated or overestimated, we argue we have provided an improved understanding of this issue, regardless of the presence of all the factors that have confounded the general scenario.

Author Contributions: Not applicable as this study was completely conducted by just one author.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable as this study has involved neither humans nor animals.

Informed Consent Statement: Not applicable as this study has not involved humans, but only aggregated, anonymized data.

Data Availability Statement: All data used for the peak detection analysis described in this paper are available at the following public repositories. Percentage excess mortality: https://github.com/owid/covid-19-data/tree/master/public/data/excess_mortality. Daily confirmed COVID-19 deaths: https://github.com/owid/covid-19-data/tree/master/public/data/jhu. The results of all the calculations are fully reproducible by using the methods presented in the paper. Given the simplicity of the described procedures, the calculation of interest can be conducted with a simple calculator and a spreadsheet to record the data, without any need to resort to computer code.

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