Proposed journal: [JECH](https://jech.bmj.com/pages/authors/#original_research) as original research; Consider accompanying essay focused on UK and COVID?

JECH original research:

**Word count:** up to 3000 words currently 3738

**Abstract:** maximum of 250 words (Background, Methods, Results and Conclusion) needs cutting too  
**Tables/Illustrations:** up to 5   
**References:** up to 40 currently 37

**Title:** What can lifespan variation reveal that life expectancy hides? Comparison of five high-income countries.

**Authors:**

* Lucinda Hiam (corresponding author), DPhil candidate, School of Geography and the Environment, University of Oxford, South Parks Road, Oxford OX1 3QY. [Lucinda.hiam@kellogg.ox.ac.uk](mailto:Lucinda.hiam@kellogg.ox.ac.uk)
* Jon Minton, Public Health Intelligence Adviser, Public Health Scotland.
* Martin McKee, Professor of European Public Health, London School of Hygiene and Tropical Medicine.

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**Contributions:** JM conceived the idea for this paper and carried out all the data extraction and analyses. LH drafted the first version, with significant edits and input from JM and MM.

**Competing interests:** none declared

**Key words:** public health, mortality, health inequalities

**Data availability:**

* Data are available in a public, open access repository
* Data are available from the Human Mortality Database: <https://www.mortality.org/>
* Code and analyses used are available from GitHub: <https://github.com/JonMinton/rising_tide> (accessed 22nd September 2020)

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## *What is already known on this subject?* In two or three sentences explain what the state of scientific knowledge was in this area before you did your study and why this study needed to be done. Be clear and specific.

Lifespan variation is a measure that complements one of the most widely used measures of population health, life expectancy, by capturing the distribution of age at death in a population. It typically decreases as life expectancy increases, but research in the USA, where life expectancy has fallen since 2015, showed it decreasing prior to any changes seen in life expectancy. In recent years the UK has seen stalls in life expectancy at birth. We ask whether lifespan variation might have given early warning of these developments, and compare to other high-income countries.

## *What this study adds?* Give a simple answer to the question “What do we now know as a result of this study that we did not know before?”. Be brief, succinct, specific, and accurate. You might use the last sentence to summarise any implications for practice, research, policy, or public health.

In the UK and USA, previously reducing trends in life disparity reversed, prior to the appearance of deteriorations in growth of life expectancy. In Canada, life disparity has begun to increase but life expectancy has not yet been significantly impacted. In all 3 nations, worsening mid-age mortality has contributed to these changes. By contrast, Japan continues to follow previous trends in these measures. Measuring life disparity may allow policy makers to identify changes in mortality trends that might have otherwise been missed.

# Abstract needs cutting should be 250w

## Background

Life expectancy at birth (e0) has tended to improve over time in most countries for many decades. But in recent years, the USA and UK have seen previous trends in improving life expectancy stall and, in the USA, decline. Another important and related population health measure is lifespan variation, which worsened in the USA a few years before the fall in life expectancy at birth.

## Methods

We calculated life expectancy and life disparity (a type of lifespan variation) for five countries (USA, UK, France, Japan and Canda) using sex-and age-specific mortality rates for from the Human Mortality Database, for1975 to 2017. Finally, we present trends in age-specific mortality to identify the age groups contributing to these changes.

## Results

The UK, USA and Canada show stalls and falls in life expectancy for both males and females, with rising life disparity preceding these changes. These changes are driven by worsening mortality in mid-age for males and females in the USA, and males in the UK. Japan by contrast continues along previous trajectories.

## Conclusion

Something unusual is happening in mid-age in the USA and the UK when compared to other high-income countries. It demonstrates that life disparity is a useful complementary measure to use alongside life expectancy at birth, and that governments must focus on interventions to reduce premature mortality and inequalities in order to see continued improvements in life expectancy. The data from Japan demonstrate that economic growth is not necessary for continued population health improvements.

# Introduction

Life expectancy at birth (denoted e0) is a highly efficient single parameter summary of population health and how it changes over time. Absent of extraordinary events – such as wars and pandemics – for most of the last few decades e0 has tended to trend steadily upwards in most populations.1 Where e0 has fallen it has usually been associated with major adverse population exposures, such as the AIDS pandemic, wars, famines, or state collapse (as for populations formerly part of the USSR).;2 the impact of the COVID-19 pandemic is not yet known.3

The trends in e0 over time have been consistent enough in most higher-income nations that even stalling rather than simply falling life expectancy trends, i.e. falls much slower than the long-term average, are concerning and should demand attention and explanation. The cause of a falling e0 may only start to become clear by looking carefully at different demographic subgroups within the population, including differences by sex and age group, and differences by cause of death. Similarly, rapid improvements in some subgroups may to some extent ‘offset’ and so conceal concerning declines or stalls in other subgroups. For example, in the 1980s, concern about the slowdown in what had, until then, been increasing life expectancy in countries of Central and Eastern Europe might have been greater if it had been widely recognised that the continued improvement in mortality in infancy and childhood was obscuring a worsening in adult mortality.4 Similarly, a transient slowing in the rate of improvement in life expectancy in Spain in the 1980s concealed an approximate doubling of mortality in young adult men, largely due to HIV/AIDS and road traffic deaths.5 Like any summary measure, e0 can conceal details that may have practical or policy importance, and so should be complemented by other population health measures which may reveal what e0 alone conceals.

Lifespan variation is a complementary measure to e0. It measures the average gap between the age at death of an individual and the remaining life expectancy at that age. (See XXX for example – or appendix?) 6 Historically, as life expectancy has increased, lifespan variation has decreased, and those countries with the highest life expectancy also have the lowest lifespan variation.6 This phenomenon has also been observed in other primate species.7

The usual coupling of rising life expectancy with falling lifespan variation suggests a demographic analogue of the political slogan, “a rising tide raises all boats” – i.e. that as the tide (life expectancy) increases so the individual mortality risks at different ages (the ‘boats’) will each fall too, often in lockstep. If they do not, then lifespan variation will increase rather than fall. 8 In the USA, for example, life expectancy increased by approximately 10% for men and 5% for women over 1980 -2014, but lifespan variation fluctuated then increased. Life expectancy in the USA then declined every year since 20159 driven by what have been termed “deaths of despair”,10 11 from alcohol, other drugs, and suicide.11 The authors argued that had lifespan variation been monitored more closely, the mid-life mortality crisis in the USA could perhaps have been identified earlier.8

Here we extend the analysis of lifespan variation to four other high-income countries: the UK, where like the USA, gains in life expectancy have trailed behind those in other industrialised countries,12 Japan, which has seen sustained progress, and France and Canada, neighbours of the UK and USA respectively, which lie in the middle. We show how life expectancy and lifespan variation in combination can be used to a) identify changes that could otherwise be missed and b) detect changes in trends earlier. We also highlight that to understand health, and, to some extent, economic outcomes by country in the context of the current COVID-19 pandemic, first the health of the population prior to 2020 must be explored.

# Methods

## Data source

We extracted sex- and age-specific mortality rates from the Human Mortality Database (HMD) from 1975 until the latest available year (2017 or later) for the USA, Japan, UK, France, and Canada. Ethical approval was not required.

## Analytical approach

First, we report e0. Second, we measure life disparity, a method used to calculate lifespan variation over time, replicating the method used by Vaupel et al.6 The code and analyses carried out can be found on Github[[1]](#footnote-1). Finally, we present trends in age-specific mortality to identify the age groups contributing to these changes.

# Results

Figure 1 shows the contribution to overall life disparity from mortality at different ages, using the example of Japan for 1947, 1975 and 2017. The top row shows the improvements in period survival by age over time, with age on the x axis and the proportion of people surviving to a given age on the y axis. Over time, as people live longer, the curve shifts to the right. The lower row shows the contributions to life disparity of different ages: infancy on the left , early childhood and adulthood on the right. In 1947 life disparity was driven both by both infant mortality and mortality risk throughout working and retirement ages, and by 2017 lifespan disparity is largely due to older ages.

Chart, histogram

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Figure 1: Changing mortality hazard and lifespan disparity contributions in Japan, 1947, 1975 and 2017

Figures 1a and 1b in the web appendix repeat Figure 1 for the USA, to allow USA- Japan comparison. This comparison shows that lifespan disparity was higher in Japan than the USA in 1947, but by 2017 was higher in the USA, with both infant mortality and older working and retirement age mortality risks higher, and ‘spread across’ older adult ages.

## Life expectancy at birth and life disparity

Next, we present trends in life expectancy at birth and life disparity for each country from 1975 to at least 2017. Japan has had the highest e0 for females since approximately 1980 and for males from 1975, and improved annual, except for a brief fall after 2011, coinciding with the 2011 Tōhoku earthquake and tsunami, when almost 16,000 people were killed on one day.13 For females, the USA and UK consistently perform worst, with stalling improvements from 2010 onwards. A similar pattern is seen for males, although France also appears to perform poorly. Canada shows steady progression for both males and females, with a slight stalling seen for males in most recent years.

For life disparity, all countries a downward trend between 1975 and 2000, albeit with a transient interruption among males in France and the USA in the 1980s and among females in Japan in the 1990s. Since 2010 life disparity has increased markedly in Canada and the USA, and slightly in the UK, also. Life disparity was increased for 2011 for males especially, which may reflect the impact of the earthquake, before falling again.

Chart

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Figure 2: Life expectancy at birth (top) and life disparity over time (bottom) 1975 to 2017

Figure 3 zooms in on life disparity since 2000, since the majority of changes occur after 2010. Increases in life disparity in USA, Canada, and the UK are even clearer.

A close up of a map

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Figure 3: Life disparity for females and males 2010 to 2017

## Probability of dying in the next 12 months

Which age groups are driving changes in life disparity? To answer this we next examine 12 month death risks at birth, 40, 80 and 90 years of age. (See White13 and Christensen.14) In Figure 4, the y axis is log scale; straight line mean constant percentage rate reduction per year over time. For some countries/ages, (older Japanese females), the series looks like a straight line, but for others it does not. At aged 40 years, figure 4 shows a reversal of improving trends in mortality at aged 40 years for all countries, with worsening mortality since 2010, more marked in some populations.

A close up of a map

Description automatically generated

Figure 4: Probability of dying in the next 12 months by age in years, 1975-2017

At aged 0, previously declining trends reversed in the UK, France and Canada, in females, and in males for the UK and France. Although the USA has the highest risk, trends have not reversed. Conversely, at aged 40, the USA has markedly higher risk for both sexes, clearly increasing since 2010, more markedly in males. In Canada, and the UK, risk at age 40 increased more recently. In France trends continued to improve. At ages 80 and 90 years, the USA no longer has the highest risk; the UK does.

## To what extent are mortality trends at different ages log-linear in the five countries?

It is unfeasible to show the series in Figure 4 for each individual age, as this would require 111 graphs, but we can summarise the straightness or consistency in improvement by calculating the correlation in logged age-specific mortality rates at different ages over a fixed period of time, as R-squared for each individual age. If traditional demographic assumptions are correct,15 the correlation in logged mortality rates over time, within a population, should be close to 1; a high R-squared indicates straighter, more consistent and continual improvement over time.

This analysis draws on two key assumptions made in some of the most well-used families of demographic forecasting models, starting with Lee-Carter’s paper:15 first, that mortality trends at all ages within a high-income population (USA in the original example) change at similar percentage rates over time, improving in ‘lock step’ with each other, and second, that this percentage rate of change over time remains constant over long periods. This is referred to as the population’s ‘drift’ parameter in the modelling approach. Both of these assumptions, that there remains a fixed ‘drift’ in improvement, and that this ‘drift’ affects all ages’ percentage mortality change over time equally, can be investigated empirically. If the assumption of a fixed ‘drift’ in improvement were appropriate, then the model fit (R-squared) of log mortality at each age over time would be close to 1; and if the assumption that this ‘drift’ applies to all ages equally were appropriate, then the correlation (r) in log-mortality rate trends at all ages would be close to 1. This modelling assumption can be explored empirically by calculating the correlation in logged age-specific mortality rates at different ages over a fixed period of time. If the assumption were appropriate, then the correlation in logged mortality rates over time, within a population, will be close to 1.

Figure 5 shows the extent to which mortality trends at different ages are log-linear in the five countries.

A close up of a map

Description automatically generated

Figure 3: Linearity in log mortality improvement rates, males and females, 1975 to 2017

If mortality trends at all individual ages are each log-linear, a horizontal line at ‘1’ will be evident for all populations. Dips below 1 indicate that for some ages trends are less consistent and continuous. In general, trends are largely log-linear age at 0, and between around age 55-80 years for all populations. Deviations from log-linearity are more pronounced from after around age 80-90, and in younger working ages; differences between countries are also greatest at these ages, which also differ by sex. There is greatest departure from log-linearity in the USA, most pronounced near age 30, and in the USA (and Canada for males) departure from log-linearity begins at younger elderly ages than in other populations.

The key finding here is how different the trajectories for the UK and USA are. There is a clear lack of constant improvement trends in young adulthood in males in the UK, and both sexes in the USA, suggesting something unusual is occurring in these cohorts. The possibility of the deviation from linearity could be due to these age groups seeing faster improvements than other groups, but we are able to exclude this due to the results shown in Figure 4 of worsening mortality risk in the same age groups (40 years).

This approach represents a novel contribution, as the detachment in log-linearity in improvement rates suggest adverse social factors in those of working age that appear to, in the first instance, affect lifespan disparity, and male life expectancy trends.

# Discussion

We tested two demographic assumptions. First, that lifespan variation decreases as life expectancy increases.6 Second, that mortality improvements at different ages should occur in ‘lockstep’ with each other, demonstrating linearity.15 16 Of the 5 countries examined, the USA, UK and Canada have deviated from improving trends in both life expectancy and lifespan variation. In addition, even though the assumptions of log linearity and correlation in trends at different ages were built into a model designed to forecast mortality trends in the USA, we can see that it is within the USA that the greatest violations in these assumptions are observed, followed by the UK. By contrast, both types of assumption largely hold for Japan, and, to a lesser extent, France.

In the USA, UK and Canada, the departure from previous improving trends in improving life expectancy was preceded by increases in life disparity, driven by an increase in working-age mortality. These findings reiterate the importance of looking beyond aggregate measure of health.17

## What is happening in mid-age in the UK and the USA?

The USA has seen an unprecedented reversal in life expectancy, with decreases seen every year since 2015.18 Explanations given include mid-age ‘deaths of despair’(deaths from suicide, drug and alcohol overdoses, and alcoholic liver disease),10 11 and more recently stagnation in rates of cardiovascular diseases (CVD) mortality improvement, which improved markedly from 1970 to 201019 . The USA’s adverse population health trends have been attributed largely to ‘worsening health among working-age individuals of lower socioeconomic status’. Wide ranging evidence on the impact of economic precarity on health, throughout the life course, is needed to support policy-makers.17

In the USA, both ‘despair-related’ and cardiovascular deaths are more prevalent in the most deprived, with wide racial and income disparities demonstrated in outcomes, and similar risk factors of both development and severity, such as smoking, obesity, and psychological stress.

Similarly, the UK has had a decade of austerity and worsening health outcomes: stalling life expectancy, rising infant mortality rates, widening inequalities and spending on health and social care that failed to keep pace with demand.20 21 Furthermore, in-keeping with the findings of this study is evidence showing rising mid-age mortality (aged 45-54 years) due to ‘deaths of despair’ in England.22 While the debate continues on whether to prioritise protecting health or the economy during COVID-19, though the reality is far from as simple as a binary decision,23 it is clear England has managed to do neither, with the highest excess mortality in Europe from January to June 2020,24 and the UK one of the worst economic declines when compared with 38 countries where GDP data are available.25

*Add ref to CVD work of Mike Murphy*

In both the UK and USA, the stalling and falling life expectancy was shown to have been preceded by worsening life disparity, driven by mid-age mortality. This is consistent with evidence that has shown that countries who have been successful in increasing life expectancy have done so by reducing premature mortality.6 26 The more lives saved at younger ages, the stronger the relationship between life expectancy and life disparity.26

## What can be learned from Japan?

Japan is a longevity trends success story.27 With the exception of raised life disparity in 2011, Japan continued to make good progress in the 2010s, while the USA and UK did not.

Japan’s continually improving life expectancy is not simply due to steady economic growth;27 both life expectancy and life disparity trends appear unperturbed by periods of long-term low economic growth; health health inequalities did not worsen.28 This shows that increasing disparity and stalling life expectancy trends in the UK and USA, during their periods of slower economic growth, are not inevitable, and may be in part due to political choices, including austerity in the UK, and economic and drugs policies in the USA.

*Consider ref Wada et al occupational and link to uk/usa29*

## What implications does this have for understanding the COVID-19 response?

At the time of writing, COVID-19 dominates both health and political discourse. Our findings include that life expectancies, life disparities, and midlife mortality trends are less favourable in the USA and UK than comparator nations, even before the pandemic; evidence of higher excess and COVID-related deaths in the USA and UK may therefore be no coincidence. Those countries that entered the pandemic with better and more consistent health trends seem to have better mitigated the negative effects of the economic shock, and been less likely to see excess mortality from non-COVID deaths. These areas of course require substantial further investigation, but it is noteworthy that when both changes to the economy (measured as change in GDP) and confirmed deaths due to COVID-19 are compared, Japan is once again an outlier with substantially lower changes in both measures.25

## Strengths and weaknesses of the study

The Human Mortality Database has rigorous data quality requirements and standardisation procedures, and are widely accepted as reliable for international comparison.30 The methods used to calculate life disparity and probability of dying at 12 months replicate those of experts in the field, and were checked against code supplied by one of the pioneers in using these methods.6 13 14 We also examine trends rather than year-on-year changes, as it has been suggested these are more useful due to annual fluctuations.31 Comparison of the countries with the best and worst rates were those identified by the ONS,12 thus removing bias of country selection, and comparison with geographically and politically similar nations demonstrated reversal of trends is not inevitable, as well as the unexpected finding of Canada’s deteriorating life disparity.

There are some limitations. For example, the UK is treated as a single entity, concealing differences between the devolved nations. This has been shown to be important, for example in Scotland where intentional investment was made to reduce IMR, with good effect, and more recently, the devolved nations varying responses and policy decisions during COVID-19.

Furthermore, the data are aggregated, so it is not possible to examine differences by factors such as race, employment status, and others outlined below. In addition, although political and economic decisions by states are of huge importance in population health, and ‘natural experiments’ are a key way to investigate these,17 32 unavoidably, it is difficult to assert causality when the association between the data and policy implementation is correlation only. Even so, Bradford Hill’s criteria can be of use in considering causality in the absence of alternative methodology.33

Finally, examining five countries in this paper has meant each individual trajectory could not be considered in depth, nor could all fluctuations be explored, leaving many unanswered questions. This is considered further under ‘future research’.

## Future research and unanswered questions

These observations should encourage more detailed analyses of each country. Firstly, the ‘social gradient’ in health outcomes is well-documented in both the UK and the USA.34 35 Examining life disparity through the lens of the social determinants of health—to include analysis of factors such as educational level, housing, income and employment—would undoubtedly reveal deeper disparities, but may also provide information vital for targeted public health interventions and health policy implementation.

Secondly, these aggregate data do not allow for exploration of the impact of race and ethnicity. As with many health outcomes, in the UK the impact of COVID-19 on people from Black Asian Minority Ethnic backgrounds has been disproportionately high,36 and while official analyses noticeably ignored the role of structural, systemic racism, others called for urgent investigation.37

Thirdly, although the data are presented by gender, further analysis of the differences have not been carried out and are essential to fully understand the implications of what is seen. For example, in England, women in the most deprived areas saw a fall in life expectancy between 2010-2012 and 2016-2018.35 Fourthly, Canada was selected as a geographical neighbour to the USA, but revealed an unexpected finding. This requires further investigation of its own into health inequalities in Canada, and previous trends. Finally, although the overall impact of the COVID-19 pandemic will not be known for some time, inter-country comparison must look at the preceding decades to fully understand the outcomes seen.

# Conclusion

The data presented here show that the worsening of life expectancy and life disparity in the USA and the UK were not inevitable, and neither are the continuing downwards trends. France and Japan both experienced periods of downturn but recovered and have been able to continue with improving trajectories in both life expectancy and life disparity. The evidence suggests that governments must focus on reducing inequalities, and in particular premature mortality, in order to improve life expectancy and to decrease life disparity.

# References

1. Hiam L, Dorling D, Harrison D, et al. What caused the spike in mortality in England and Wales in January 2015? *Journal of the Royal Society of Medicine* 2017:141076817693600. doi: 10.1177/0141076817693600 [published Online First: 2017/02/17]

2. McMichael AJ, McKee M, Shkolnikov V, et al. Mortality trends and setbacks: global convergence or divergence? *Lancet* 2004;363(9415):1155-9. doi: 10.1016/s0140-6736(04)15902-3 [published Online First: 2004/04/06]

3. Aburto JM, Kashyap R, Scholey J, et al. Estimating the burden of COVID-19 on mortality, life expectancy and lifespan inequality in England and Wales: A population-level study. *medRxiv* 2020:2020.07.16.20155077. doi: 10.1101/2020.07.16.20155077

4. Chenet L, McKee M, Fulop N, et al. Changing life expectancy in central Europe: is there a single reason? *Journal of public health medicine* 1996;18(3):329-36. doi: 10.1093/oxfordjournals.pubmed.a024514 [published Online First: 1996/09/01]

5. Chenet L, McKee M, Otero A, et al. What happened to life expectancy in Spain in the 1980s? *Journal of epidemiology and community health* 1997;51(5):510-4. doi: 10.1136/jech.51.5.510 [published Online First: 1998/01/13]

6. Vaupel JW, Zhang Z, van Raalte AA. Life expectancy and disparity: an international comparison of life table data. *BMJ Open* 2011;1(1):e000128. doi: 10.1136/bmjopen-2011-000128

7. Colchero F, Rau R, Jones OR, et al. The emergence of longevous populations. *Proceedings of the National Academy of Sciences* 2016;113(48):E7681-E90. doi: 10.1073/pnas.1612191113

8. van Raalte AA, Sasson I, Martikainen P. The case for monitoring life-span inequality. *Science* 2018;362(6418):1002-04. doi: 10.1126/science.aau5811 [published Online First: 2018/12/01]

9. Arias E. XJ. United States Life Tables, 2017 National Vital Statistics Reports2019 [updated 24 June 2019; cited 2019 1 November]. Available from: <https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_07-508.pdf> accessed 1 November 2019.

10. Case A, Deaton A. Rising morbidity and mortality in midlife among white non-Hispanic Americans in the 21st century. *Proceedings of the National Academy of Sciences* 2015;112(49):15078-83. doi: 10.1073/pnas.1518393112

11. Case A. DA. Mortality and Morbidity in the 21st Century Brookings Papers on Economic Activity,: Brookings Institution Press; 2017 [updated Spring 2017. pp. 397-476]. Available from: <https://muse.jhu.edu/article/671752/pdf?casa_token=bhG_ucDpXQcAAAAA:V0KMLbgIjulqGNMedAEbKWe0EDxixZevy5LjZKylJu_DgDugqpbM9Avn9CMpO6GR8ZlvEFtL6hk> accessed 28 October 2019.

12. Office for National Statistics. Changing trends in mortality: an international comparison: 2000 to 2016 2018 [updated 7 August 2018; cited 2018 11 August]. Available from: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/articles/changingtrendsinmortalityaninternationalcomparison/2000to2016> accessed 11 August 2018.

13. White KM. Longevity Advances in High-Income Countries, 1955–96. *Population and Development Review* 2002;28(1):59-76. doi: 10.1111/j.1728-4457.2002.00059.x

14. Christensen K, Doblhammer G, Rau R, et al. Ageing populations: the challenges ahead. *The Lancet* 2009;374(9696):1196-208. doi: <https://doi.org/10.1016/S0140-6736(09)61460-4>

15. Lee RD, Carter LR. Modeling and Forecasting U.S. Mortality. *Journal of the American Statistical Association* 1992;87(419):659-71. doi: 10.1080/01621459.1992.10475265

16. Lee R. The Lee-Carter Method for Forecasting Mortality, with Various Extensions and Applications. *North American Actuarial Journal* 2000;4(1):80-91. doi: 10.1080/10920277.2000.10595882

17. Venkataramani AS, O’Brien R, Whitehorn GL, et al. Economic influences on population health in the United States: Toward policymaking driven by data and evidence. *PLOS Medicine* 2020;17(9):e1003319. doi: 10.1371/journal.pmed.1003319

18. Woolf SH, Schoomaker H. Life Expectancy and Mortality Rates in the United States, 1959-2017. *JAMA* 2019;322(20):1996-2016. doi: 10.1001/jama.2019.16932

19. Mehta NK, Abrams LR, Myrskylä M. US life expectancy stalls due to cardiovascular disease, not drug deaths. *Proceedings of the National Academy of Sciences* 2020;117(13):6998-7000. doi: 10.1073/pnas.1920391117

20. Hiam L, Dorling D, McKee M. Things Fall Apart: the British Health Crisis 2010-2020. *Br Med Bull* 2020;133(1):4-15. doi: 10.1093/bmb/ldz041 [published Online First: 2020/03/29]

21. Marmot M. Why did England have Europe's worst Covid figures? The answer starts with austerity 2020 [updated 10 August 2020; cited 2020 22 September]. Available from: <https://www.theguardian.com/commentisfree/2020/aug/10/england-worst-covid-figures-austerity-inequality> accessed 22 September 2020.

22. Joyce R. XX. Inequalities in the twenty-first century 2019 [updated 14 May 2019; cited 2019 28 October]. Available from: <https://www.ifs.org.uk/inequality/wp-content/uploads/2019/05/The-IFS-Deaton-Review-launch_final.pdf> accessed 28 October 2019.

23. Peeples L. How the next recession could save lives Nature2019 [updated 23 January 2019; cited 2020 22 September]. Available from: <https://www.nature.com/articles/d41586-019-00210-0> accessed 22 September 2020.

24. Office for National Statistics. Comparisons of all-cause mortality between European countries and regions: January to June 2020 2020 [updated 30 July 2020; cited 2020 22 September]. Available from: <https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/comparisonsofallcausemortalitybetweeneuropeancountriesandregions/januarytojune2020> accessed 29 August 2020 2020.

25. Hasell J. Which countries have protected both health and the economy in the pandemic? Our World in Data2020 [updated 1 September 2020; cited 2020 22 September]. Available from: <https://ourworldindata.org/covid-health-economy> accessed 22 September 2020.

26. Aburto JM, Villavicencio F, Basellini U, et al. Dynamics of life expectancy and life span equality. *Proceedings of the National Academy of Sciences* 2020;117(10):5250-59. doi: 10.1073/pnas.1915884117

27. Marmot MG, Smith GD. Why are the Japanese living longer? *British Medical Journal* 1989;299(6715):1547-51. doi: 10.1136/bmj.299.6715.1547

28. Hiyoshi A, Honjo K, Platts L, et al. OP86 Low economic growth, health, health inequalities and sustainable development goals in a rich country: 27-year Japanese time series. *Journal of epidemiology and community health* 2020;74(Suppl 1):A40-A41. doi: 10.1136/jech-2020-SSMabstracts.85

29. Wada K, Kondo N, Gilmour S, et al. Trends in cause specific mortality across occupations in Japanese men of working age during period of economic stagnation, 1980-2005: retrospective cohort study. *BMJ (Clinical research ed)* 2012;344:e1191. doi: 10.1136/bmj.e1191

30. Human Mortality Database. Overview 2020 [cited 2020 11 August]. Available from: <https://www.mortality.org/Public/Overview.php> accessed 11 August 2020.

31. Minton J, Fletcher E, Ramsay J, et al. How bad are life expectancy trends across the UK, and what would it take to get back to previous trends? *Journal of epidemiology and community health* 2020;74(9):741-46. doi: 10.1136/jech-2020-213870

32. Fuchs VR. Social Determinants of Health: Caveats and Nuances. *JAMA* 2017;317(1):25-26. doi: 10.1001/jama.2016.17335

33. Hiam L, Dorling D, McKee M. The cuts and poor health: when and how can we say that one thing causes another? *Journal of the Royal Society of Medicine* 2018;111(6):199-202. doi: 10.1177/0141076818779237 [published Online First: 2018/06/08]

34. Chetty R, Stepner M, Abraham S, et al. The Association Between Income and Life Expectancy in the United States, 2001-2014. *JAMA* 2016;315(16):1750-66. doi: 10.1001/jama.2016.4226

35. Institute of Health Equity. Health Equity in England: the Marmot Review 10 Years On 2020 [updated February 2020; cited 2020 22 September]. Available from: <http://www.instituteofhealthequity.org/resources-reports/marmot-review-10-years-on> accessed 22 September 2020.

36. Public Health England. Disparities in the risks and outcomes of COVID-19 2020 [updated August 2020; cited 2020 22 September]. Available from: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908434/Disparities_in_the_risk_and_outcomes_of_COVID_August_2020_update.pdf> accessed 22 September 2020.

37. Patel P, Hiam L, Sowemimo A, et al. Ethnicity and covid-19. *BMJ (Clinical research ed)* 2020;369:m2282. doi: 10.1136/bmj.m2282

1. <https://github.com/JonMinton/rising_tide> accessed 22nd September 2020 [↑](#footnote-ref-1)