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

JECH original research:

**Word count:** up to 3000 words  
**Abstract:** maximum of 250 words (Background, Methods, Results and Conclusion)  
**Tables/Illustrations:** up to 5  
**References:** up to 40

## *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.

Life expectancy at birth is a measure of population health. Lifespan variation is a complementary measure, which should decrease as life expectancy increases. Recent years have seen the USA and the UK see falls and stalls in life expectancy at birth—were these preceded by changes in life disparity, and could this have therefore been detected earlier?

## *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, life disparity trends reversed to increase prior to deteriorations in life expectancy. In Canada, life disparity trends have begun to reverse but life expectancy has not yet been consistently impacted. In all 3 nations, worsening of mid-age population mortality has contributed to these changes. Measuring life disparity could allow policy makers to detect changes in trends earlier and identify changes that might have otherwise been missed.

# Abstract

## Background

## Methods

## Results

## Conclusion

# Introduction

Life expectancy at birth has the considerable benefit of providing a single figure that captures the overall mortality experience of a population. In the absence of data artefact, a wide-scale environmental event such as war or natural disaster, a disease epidemic or mass in- or out- migration, life expectancy should can be expected to continue to improve in the populations of high income countries (HICs).1 Indeed, over the last century there have been only a few situations in which life expectancy has actually fallen, including wars, the AIDS pandemic, and the large scale social disruption that followed the collapse of the Soviet Union.2 The impact of the COVID-19 pandemic is not yet known. However, there have been more cases where life expectancy improvements have slowed or stalled. When examined in detail, this often reflects reversals in some age groups that may, to some extent, be compensated for by continued progress in others. 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.3 Similarly, what seemed like 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.4 Thus, like any summary measure, life expectancy can conceal variation that may have practical or policy importance.

This calls for complementary summary measures that capture differences in the progress attained by different age groups in reducing mortality, and hence improving life expectancy. One such measure is lifespan variation. This measures the average gap between the age at death of an individual and the remaining life expectancy at that age. To take the example used in the seminal paper by Vaupel and colleagues,5 the 2008 life table for Sweden produced a figure for life expectancy at birth of 83 years and of a further 7.5 years for those reaching the age of 83. Someone dying at birth would therefore lose 83 years while someone dying at age 83 would lose 7.5 years. Historically, as life expectancy has increased, lifespan variation has decreased, and those countries with the highest life expectancy also have the lowest lifespan variation.5 This phenomenon is not unique to humans: it has been observed in primate species ‘separated [from humans] by millions of years of evolution and over hundreds of years of human social progress’.6

These observations have given rise to the idea that a “rising tide raises all boats”, whereby progress in life expectancy should, in normal circumstances, reflect reductions in mortality at all ages and that lifespan variation should be considered alongside life expectancy when monitoring the progress of nations.7 A recent example can be seen in the USA, where life expectancy increased by approximately 10% for men and 5% for women between 1980 and 2014, but lifespan variation fluctuated markedly, eventually increasing even while life expectancy increased, in a departure from historical trends. Life expectancy in the USA has subsequently declined every year since 20158 driven by what have been termed “deaths of despair”,9 10 due to due to drug and alcohol overdoses, suicides, and alcohol-related liver disease.10 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.7

In this paper 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,11 Japan, which has seen sustained progress, and France and Canada, neighbours of the UK and USA respectively, which lie in the middle. We argue that this measure complements life expectancy and show how it can be used to a) identify changes that could otherwise be missed and b) detect changes in trends earlier.

# 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?) for the following countries: the USA, Japan, the UK, France, and Canada. Ethical approval was not required.

## Analytical approach

First, we report life expectancy at birth. Second, we measure life disparity over time, one of the methods used to calculate lifespan variation, replicating the method used by Vaupel et al.5 [?add description as appendix]

Finally, having described changes in lifespan variation through the measure of life disparity, we then calculate the trends in deaths at different ages to explore the age groups contributing to these changes.

# Results

Figure 1 shows trends in life expectancy at birth in each country from 1975 to 2017. Japan has had the highest life expectancy for females since approximately 1980 and for males from 1975, and has sustained improvements, except for a brief fall after 2011. This occurred after the 2011 Tōhoku earthquake and tsunami, when almost 16,000 people were killed on one day.12 For females, the USA and UK perform the worst comparatively, with stalling in improvements seen 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.

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Figure 1: Life expectancy at birth from 1975-2017 for females and males

However, as mentioned, life expectancy may hide some underlying trends occurring in life disparity. As life expectancy increases, life disparity should decrease. Figure 2 shows life disparity in each country over time. All displayed 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, however, there has been a clear reversal in the trends in Canada and the USA, with a slight increase in the UK, also. An increase in life disparity reflects a widening of inequalities in age at death. Japan once again sees a blip, more so in males than females, after 2011 which may reflect the impact of the earthquake.

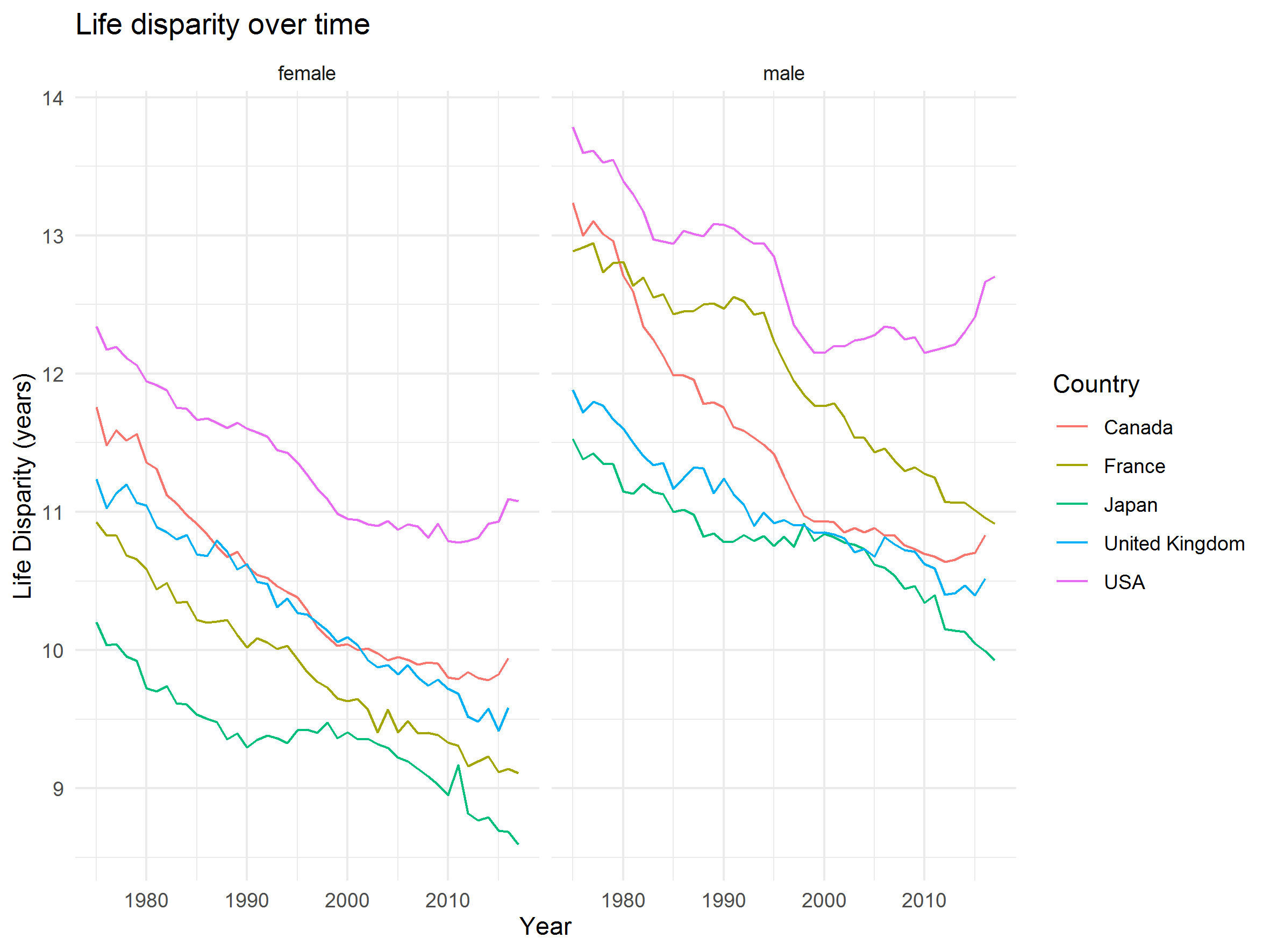


Figure 2: Life disparity for females and males, 1975-2017

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

Figure 3 demonstrates life disparity since 2000, since the majority of changes in trends occur after 2010. Here, an increase in life disparity for males and females in USA, Canada, and the UK can be seen more clearly. To investigate this, next we examine the relationship of mortality improvement rates, to understand at what age groups these changes are occurring. In a HIC, mortality improvements should improve in ‘lock step’, displaying high linearity, in-keeping with demographic assumption forecasting methods. Specifically, Lee-Carter proposed linear projections of logged age-specific death rates result in straight line projections in HICs.13 To demonstrate this concept, Figure 4 shows the relationship of mortality rates for Japan in 1947 and 2017. It is clear by 2017, improvements are linear, until older ages, compared to in 1947 where infant mortality and under-5 mortality was high.

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Figure 4: Changing mortality hazard and lifespan disparity contributions in Japan, 1947, 1975 and 2017

When the relationship of mortality improvements between different ages is examined from 1975 onwards, there is evidence of some maintaining consistent improvements and therefore stable correlation, and others where correlation reduces. Figure 5 shows how linear the percentage mortality trends are at different ages, where linearity is R-squared. This reveals the 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.

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Figure 5: Linearity in log mortality improvement rates, males and females, 1975 to 2017

The deviation from linearity could be due to these age groups seeing faster improvements than other groups, and this possibility needs to be excluded. To examine for this, Figure 6 shows the probability of dying in the next 12 months at 0 years, 40 years, 80 years and 90 years, replicating methods used by White14 and Christensen.15 This shows reversal of improving trends in mortality at aged 40 years in males and females for all countries, with worsening mortality since 2010, though some are more marked than others.

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Figure 6: Probability of dying in the next 12 months by age in years, 1975-2017

At aged 0, there is reversal of the previously declining trends of probability of death in the UK, France and Canada, in females, and in males for the UK and France. Although the USA has the highest probability of dying, the trends have not reversed. Conversely, at aged 40, the USA has markedly higher probability of dying in the next 12 months for both males and females, with a clear increase in both since 2010, though more marked in males. Canada has a more recent increase in both males and females, along with the UK. France appears to show continued improvements, while Japan has a very recent uptick of uncertain significance.

At ages 80 and 90 years, the USA no longer is the leading country with the UK highest for both males and females, converging in recent years.

# Discussion

## Statement of principal findings

In this paper, we tested two demographic assumptions. First, that in HICs life disparity, a measure of lifespan variation, should decrease as life expectancy increases.5 Second, that mortality improvements at different ages should occur in ‘lockstep’ with each other, demonstrating linearity, as shown in Figure 4.13 16 Japan and France, albeit to a lesser extent, follow these assumptions. However, in the USA, the UK, and, surprisingly, Canada, deviation from projected trends has occurred, to varying degrees, with life expectancy decreasing or stalling, preceded by life disparity increasing, and largely attributable to worsening mortality in mid-age. These findings highlight how monitoring trends in life expectancy at birth as a single summary measure of population health can conceal underlying worsening health outcomes. In particular, in Canada where life expectancy at birth does not reveal any immediate concerns, life disparity shows there are underlying problems.

## Findings per country

In Japan, life expectancy at birth is the highest in males from 1975 and males and females from the early 1980s of the 5 countries examined. The trend continues to increase over time, with one clear dip post-2011 likely attributable to the earthquake. As life expectancy continues to increase, life disparity continues to decline, again with a blip in both males and females post-2011. Log mortality improvement rates 1975 onwards demonstrates linearity in both males and females with slight deviation below 1 at around 30 years. Probability of dying in next 12 months has decreased for all ages examined over time, with a slight uptick in both males and females aged 40 years in the most recent years.

In France, life expectancy at birth is 2nd for females since 1980 and has followed a similar trajectory to the UK for males, with an overall increase with some fluctuations. Life disparity for both males and females follow a downwards trend since 1975. Linearity in log mortality improvements rates for females remains close to 1 throughout the life course, and males has a light dip at 30 years.

Probability of dying in the next 12 months by age in years has decreased for both males and females aged 40, 80 and 90 years, but with some stalling in improvements at aged 0 years.

In the USA, life expectancy has decreased in males since 2012 and stalled in females, preceded by an increase in life disparity from 2010 in both males and females. Linearity in improving mortality rates is lost at mid age, with the probability of dying in the next 12 months increasing in males and females from 2010 at aged 40 years.

In the UK, life expectancy at birth been increasing with some fluctuations until 2010 when it stalled in both males and females. Life disparity increased overall in females from 2013 and males from 2011. Linearity in log mortality improvement rates falls from approximately aged 20 to 45 years in males, with a smaller deviation from 1 in females. Probability of dying in the next 12 months increases for males and females aged 0 from 2012, in males and females aged 40 from 2012, and stalls in improvements at older ages.

In Canada, life expectancy at birth has steadily increased in males and females, with slight early signs of stalling in males in recent years. However, concerningly, life disparity in females has increased since 2010 and since 2012 in males. Linearity in log mortality improvements rates for both males and females correlate from aged 45 and 60 years onwards respectively, with fluctuations in both until then. At aged 40 years, the probability of dying in next 12 months b increases for both males and females fluctuates but increases in males from approximately 2012 and females from 2014.

## Strengths and weaknesses of the study

The study uses data from the Human Mortality Database. These data are reported following a uniform set of procedures for each population, and although there are potential errors, such as age heaping and age exaggeration, are widely accepted as reliable and comparable.17 The methods used to calculate life disparity and probability of dying at 12 months replicate those of experts in the field, and were checked [Jon]…5 14 15 We also examine trends rather than year-on-year changes, as it has been suggested these are more useful due to annual fluctuations.18 Comparison of the countries with the best and worst rates identified by the ONS11 removes 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 reported as one summary statistic, 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, and more recently, Scotland’s response to COVID-19.

Furthermore, the data are aggregated, so it is not possible to examine for the effects of inequalities, or factors such as race, employment status, and others. Clearly political and economic choices by nation states are of huge importance in population health, and it is vital to explore these when looking at health outcomes. However, unavoidably, it is difficult to assert causality when the association between the data and policy implementation is correlation only. Even so, frameworks such as Bradford-Hill can be of use in considering causality in the absence of alternative methodology.19

Finally, examining 5 nations in this paper has meant each individual country could not be considered in depth, nor could all fluctuations be explored, leaving many unanswered questions. This is considered further under ‘future research’.

## Meaning of the study

Successful countries increase life expectancy by reducing premature mortality20 – narrowing inequalities

LE and LS equality moved in opposite directions due to larger improvements in mortality at older ages or a slowdown in declines in midlife mortality20—neither of these have occurred here but an increase in midlife mort

Life span equality influences decisions people make about their lives (14)

The findings that those countries with worsening mortality at younger ages have

he strength of the relationship between life expectancy and life span equality is not co- incidental but rather a result of progress in saving lives at specific ages: the more lives saved at the youngest ages, the stronger the relationship is.

The country comparisons show these outcomes are not inevitable, but the result of policies which widen inequalities and…

The UK are the only nation of those examined to have seen an increase in IMR

Consistent with deaths of despair, mid life mortality studies and national data

UK and USA deaths of despair and rising inequalities

What’s happening in Canada

COVID—how deal with it

<https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/comparisonsofallcausemortalitybetweeneuropeancountriesandregions/januarytojune2020>

UK highest excess mortality in Europe COVID

Austerity/widening inequalities <https://www.theguardian.com/commentisfree/2020/aug/10/england-worst-covid-figures-austerity-inequality>

## Future research and unanswered questions

* Uk vs Japan (2nd paper on lost decades of economic growth and comparing the two)
* Can Japan blip be fully attributed to the earthquake or is there more underlying it
* France (1975-1990 vs 1990 onwards) and Japan show this is not inevitable. Both countries experienced periods of downturn but recovered and have been able to continue with improving trends in both life expectancy at birth and life disparity. How different?
* COVID – how recovered based on trends? Japan recovered from earthquake with same trajectory, what will happen with COVID?
* UK ‘limped into COVID’
* USA focus
* Economic growth vs these measures

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