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Abstract and additional information

ABSTRACT

INTRODUCTION: Previous research showed that younger adult males in the USA have, since the 1950s, died at a faster rate than females of the same age. In this paper we quantify this difference, and explore possible explanations for the differences at different ages and in different years.

METHODS: Using data from the Human Mortality Database (HMD), the number of additional male deaths per 10,000 female deaths was calculated for each year from 1950 to 2000, and for each year of age from 0 to 60 years. These data were arranged as a Lexis surface and visualized using shaded contour plots. The same values were calculated over the same year and age range for some other countries for comparison.

RESULTS: Males currently experience greater excess mortality than they did in the past. Coming of age (between the ages of 15 and 25 years of age) is especially perilous for men relative to women now compared to the past in the USA; the visualizations highlight this change as important.

CONCLUSIONS: Sex differences in life expectancy are not static. While women may today have an advantage when it comes to life expectancy, in the USA this has greatly increased since the 1930s. Just as young adulthood for women has been made safer through safer antenatal and childbirth practices, changes in public policy can make the social environment safer for men.

Already Known and What this Study Adds

WHAT IS ALREADY KNOWN: In richer countries males have shorter life expectancies than females. Males engage in more risk-seeking behaviour than females, especially in early adulthood. Male ‘excess’ mortality rates in the USA grew in recent decades, especially in early adulthood.

WHAT THIS STUDY ADDS: ’Excess’ adult male mortality rates begin from the start of adulthood, and are equivalent to more than 10 additional male deaths per 10,000 female deaths, at all adult ages from 1950 onwards. Differences in middle age may be explicable in terms of biological factors (‘earlier ageing’), but differences in early adulthood are more likely to have behavioural explanations. . Because of this, there will be scope to address mortality excesses in early adulthood through public health interventions. Excess male mortality seems not to be inevitable, and in peace time was not evident in the USA before 1960.

Main Manuscript

Introduction

Women, on average, live longer than men. At various stages over the life-course, women now have the edge (1–8). Male infant mortality rates are thought to have always been higher than female infant mortality rates (4), but – until childbirth became safer – more women than men usually died in their twenties and perhaps earlier (9).

Reaching adulthood and leaving the protection (or confines) of parents or carers, leads to a jump in mortality risk for both males and females; however, the spike is noticably higher for males and females (10,11). Males now 'age' both sooner and faster than females (authors’ own calculations). Historically, and throughout the world, women of child-rearing age were had higher mortality rates than males due to material mortality risks (9). Now there are only a handful of countries where women die, on average, earlier than men, but maternal mortality remains a major, if declining, killer worldwide (12).

If long-term trends are ignored it is easy to think that sex differences are inherently biological, and so little can be done. This paper challenges that perspective by showing systematic variations in age-specific mortality differences over time and across nations.

**Trends in sex-based life expectancy differences among human and animal populations**

Other recent work has referred to these differences and some attempts have been made to explain them. Researchers from the Wittgenstein Centre for Demography and Global Human Capital and the Vienna Institute of Demography reported in 2013 in the journal Gerontology that the excess male mortality seems to result from high mortality among subpopulations, more common among men, who experience higher mortality than women and thereby bring down overall life expectancy for all men compared to women. They conclude that these differences are not natural differences but that they result from socioeconomic conditions that could ameliorated (13).

In other animals, there is evidence that males live shorter lives than females though we found no studies that claimed to be able to say definitively whether this was a natural difference or a risk-based difference, or a difference due to other causes. In other animals, the idea that the difference varies has also been explored. For example, it has been observed in populations of birds that sex-biased adult mortality predicts adult sex ratio—which affects various social processes, including male aggression, courtship behaviour and whether males or females look after the young (14).

In humans, the gap in life expectancy between men and women seems to be closing. As life expectancy rises overall, and at the same time women make fewer gains relative to men, it may be that this is because women's risk profiles now are more similar to men’s..  However, this convergence is only apparent after 1980. Men took up smoking much earlier than women (15) and so it may well be a temporary effect of women being more free to smoke in the 1960s and 1970s. Now that smoking rates for both men and women have fallen the convergence may not continue.

These trends have been reflected somewhat in public policy in Europe. In 2012 the European Union ruled it unethical and illegal to require men to pay higher rates than women for life insurance, on the basis that this amounts to unfair sex discrimination against men (16), in spite of differences in mortality risk resulting in higher mortality rates among men at most points across the life course.

The changing nature of inequality in life expectancy between men and women is rarely discussed among health inequalities researchers, presumably because it has not been considered to be an inequality resulting from unfair practices or processes. We wanted to find out whether shaded contour maps, a recently rediscovered method for visualizing Lexis surfaces, can us illuminate the issue: is there evidence that this is a natural difference, or is there evidence that this is a risk-based difference, or something else?

Methods

For each country, the mortality rate ratios were arranged into a tabular configuration known as a Lexis surface, with each row representing a different age and each column representing year (17–19). The Lexis surfaces were visualised as shaded contour maps as described in Minton, Vanderbloemen and Dorling (10), and Minton (11). Contour maps borrow conceptually from orienteering, showing how the height of a surface varies over space. Each contour is individually labelled with its particular value, and traces out a path along the surface where the height does not vary; the presence of many contour lines close together indicates a section of the surface where height varies steeply, and contour lines further apart indicate a more gradual variation over the surface.

Because the Lexis surface is of ratios, the value 5/4 should be thought of as equal in magnitude but opposite in effect to 4/5, shades are coloured red if the ratios are below 1, indicating a higher female than male mortality rate, and coloured blue if the ratios are above 1, indicating higher rates of male than female mortality. The darkness of the shade is determined by the magnitude of the logarithm of the ratios, so that 4/5 will be as dark but red as 5/4 is dark but blue. The addition of shade to the contours makes it easier to distinguish between high and low sections of the surface at a glance, although perceptual distortions due to people interpreting shades in relative rather than absolute terms mean that it should be interpreted alongside the labelled contours. Before being re-discovered by Minton and colleagues (10,11) they were used extensively by Vaupel and colleagues in the late 1980s and early 1990s (20,21). The origins of using either shading or contours to visualise demographic data are much older (22,23).

All calculations were performed using the statistical programming language R. (Version 3.1.0). The lattice package (24) was used to produce the contour plots.

**Results**

Using mortality data from the United States across a period of 60 years, we see that excess mortality has varied over time. For example, we see a “smoking cloud” of very high excess deaths of older men, beginning around the year 1970. Several decades earlier most (then younger) men smoked and far fewer women did. This “cloud“ is well known. The “cliff” in the reduction of mortality inequality by sex at younger ages in the years around 1998 has not been commented on before, or necessarily observed as clearly as we can see it in these diagrams. The difference began to increase around 1943 in the United States and intensified for the 15-25 year old age band across the 20th century, most notably around 1975 and 1990.

[Figure 1 about here]

Since 2007 in Canada and Switzerland (Figures 3a and 3g) the disadvantage men aged 20 to 40 appeared to suffer in comparison with women since 1945 appeared to evaporate. This process had been seen beginning first, since the mid 1990s, in Sweden and France (Figures 3d and  3e) and since the year 2000 in the USA, England and Wales and Japan  (Figures 1, 3b and 3f). However, in most of those countries men aged 30 in the year 2009 experienced more than 10 additional deaths per 1000 female deaths, where as in the Netherlands, England and Wales, France, Japan and Sweden, men aged 30 today experience less than 5 additional male deaths per 1000 (30 year old) female deaths. This was not the case for their fathers or grandfathers.   
Another increase in excess male mortality that appears may be a Vietnam war ‘plume,’ i.e the triangle of excess male mortality for men between 1963 and 1998. This could have been due to excess deaths among men because of the Vietnam war, and persisting effects to the health and mental health of men affected by the war.

This excess in male mortality could also have been affected by the incidence of AIDS deaths, which were far higher for men than women and higher for men aged 30-39 than for other age groups. AIDS emerged as a major cause of death in the population around 1985 and the incidence of AIDS deaths peaked between 1993-1995 before decreasing rapidly (25,26) when therapy became available around 1995 (26).

Since the age band affected in the plume is most apparent for 30 to 45 year olds, there is support for both of these hypotheses, and similarly to previous findings (10) perhaps a particularly difficult time in history for men is characterised by not just one major threat to health, but by multiple threats. Between 1963 and 1998, men in the USA faced both the Vietnam War and the Gulf War, the emergence of HIV/AIDS and multiple economic recessions which damaged their traditional role as “breadwinner.” (early 1970s, 1980s and early 1990s recessions). Most recently the USA has seen its young men disproportionately influenced by the Iraq and Afghanistan wars, and the economic crash of 2008.

Beginning around the end of the 1940s, a mortality difference for boys and young men (15-25 years old) appears, intensifies and persists across the period of available data (2010). A possibility is that this increased difference in the USA among 15-25 year olds is due to road traffic accidents, as car ownership became widespread and historically men were driving far more than women. However, the male/female ratio of road traffic deaths in the 15-24 year old age group from motor vehicle accidents decreased steadily from 4.5 in 1950 to 2.5 in 2007 (25). Therefore this does not explain the increasing excess male mortality among 15-24 year olds over this period. A counter explanation is that childbirth became safer and safer for young women, and also less common for women as they had first children later and later.

Excess mortality for men was trimmed dramatically around 1995, perhaps indicating better times for men, or worse times for women, or both simultaneously.

[Figure 2 about here]

The ‘Bathtub curves’ shown in Figure 2 illustrate how two vertical slices from the contour maps can be displayed to show the ratio of male to female mortality by age. These can be taken at any of the years from the period of available data (1933 to 2010). For illustration, Figure 2 displays two years: 1933 and 2010. From these two cross sections, it is clear that the male / female mortality ratio is different in 1933 compared to 2010. At most age groups the ratio is fairly stable, but for younger men and women, from 15 to 25 years of age, there is a large ‘hump’ of excess male mortality compared to female mortality visible in 2010. This ‘hump’ is not apparent in the curve for 1933.

[Figure 3 about here]

The excess contour plots in Figure 3 show how the USA compares to other rich developed nations including Canada, England and Wales, the Netherlands, France, Sweden, Japan and Switzerland. Looking at a comparable contour plot for Canada, there is support for these ideas. Canadian men would have been similarly affected by AIDS deaths and therapy, and by economic recession but not as much by the wars.

While excess male mortality in the USA drops off for most men after 1998, the excess male mortality continued for men who were 49 years old in 2005. This is evident by observing the continuation of the darker pink ‘plume' for 49 year olds on the USA contour map. These men would have been born in 1956, the year after the US began its involvement in the war (although the main involvement was from 1965 to 1973) (27).

Looking at those men who were 19 (the average of participants in the Vietnam war) in 1965, there is evidence of male excess mortality during the war. Comparing other rich market democracies, the triangular plume is not as evident. If anything, in England and Wales, there is a kind of a triangular plume but it occurs later than would be explained by AIDS deaths. It appears after 1990 and doesn’t drop off the way the one in the USA does. The Netherlands contrasts with the USA in that the 15-24 year old age group excess male mortality trend is the reverse of that in the USA: over time the ratio seems to lessen for15-25 year olds from the period from 1950 to 2010.   
**Discussion**During the period from 1933 to 2010 differences in male versus female life expectancy emerged, most notably among younger men ages 15-25, but also among older men who were born around 1918 and 1961. There are at least five possible hypotheses that could explain this excess male mortality. They are not completing, and in some cases they simultaneously address different aspects of the results. These will now be discussed in turn.

Firstly, it could be that those born during, and who participate in, major conflicts such as wars experience worsening health, translating as higher mortality rates as they age. Exposure to adverse events at or prior to birth was hypothesised by Barker as an important determinant of poor health in later years; in demography such affects are known as cohort effects.[add barker ref]In the contour maps it is usually fairly straightforward to identify cohorts affected at birth, as mortality rates for them are noticably different to neighbouring contours (28).  
Secondly, changes in smoking behaviour could help explain the differences among 60 year olds, which begin around 1950. Men tended to be more likely to smoke than women until around 1970 (15).

A third explanation derives from the fact that when car ownership became widespread in the USA, men were more likely to drive than women, and also to have fatal traffic accidents. This had changed by 1995 when young women were as likely to drive as young men, and though men were still more likely to die in traffic accidents, the relative incidence of motor vehicle accident deaths between men and women had lessened significantly (25), perhaps indicating that seat belt laws and airbag technology have prevented deaths in spite of traffic accidents.

A fourth explanation is that emerging infections during the 1980s such as HIV, and the human response to them in the form of immune disease followed almost always by death may have contributed to the excess male mortality during the 1980s and early 1990s, when AIDS diagnoses were more common among men than women (eg males accounted for 82.4% of all persons with AIDS during the period from 1993 to 1995). The 30-39 year old age group represented the largest proportion of the total number of people diagnosed with AIDS during 1993-1995 (45.2% of the total) (26) and protective therapy against the development of the immune disease was not available until 1995/1996. The incidence of deaths among adults with AIDS reached a peak in 1995 and declined dramatically shortly after (29).

Finally, unemployment may also have played a role across the past 80 years in excess male mortality, affecting young men most. Granados et al reported in 2014 that employees who lose their jobs are at an increased risk of death, and Blakeley et al reported in 2003 that being unemployed was associated with a twofold to threefold increased relative risk of death due to suicide compared to those who were employed (30,31) though neither study claimed to make a causal link, and Lundin et al reported in 2010 that in Sweden the association that they observed between unemployment and mortality may have been confounded by mental health problems, behavioural risk factors and socio-economic position (32).

**Sex-based life expectancy trends, USA 1933-2010**  
To our knowledge this is the first study of historical trends in the sex differences in life expectancy in the USA, but our observations are consistent with other recent studies. Mayhew and Smith reported in 2014 that there is evidence that the life expectancy difference between men and women is lessening in England and Wales, suggesting that the difference is not a natural or biological difference. While it is typical to think of elder nursing homes full of women with few men surviving as long, this may be changing for the next cohort to arrive into the oldest age groups. However, if the excess mortality among young men continues or increases then this may affect the life expectancy of subsequent cohorts, reversing the trend once again.

**Limitations**

There are some limitations to this study. First, we present the visualisations as a way to identify trends in very large datasets, but we do not promote one of the five possible hypotheses over another. It is possible that male death reporting was more refined earlier on, and that the data for women became more refined during the study period, which would affect these data and the comparability of male and female data, but this would likely have resulted in rounded estimates for age at death for women in the earlier decades, and would not have changed the results that we report here.

Another limitation of this study is that it cannot say whether there is a ‘natural / biological’ longevity advantage for women. If that were true then it could be that the period before the second World War was ‘unnatural’ for women; that is, if women do have a natural longevity edge over men, then perhaps the pre-war period when women in the USA had far fewer rights relative to men and maternal mortality was much higher was the high-risk period for women, negating their natural edge. Once equal rights, birth control and safer maternity practices had been better established, the natural advantage for women re-emerged. Alternatively there is no particular ‘natural’ difference and it is always determined by differing cultural practices.

**Further research**

Further research could look more closely at historical trends and disease-specific incidence in any of the 37 countries with available data in order to draw inferences about specific public policy changes and whether these affected one gender more than another.

If the most recent differences we see represent real trends, then the peaks in excess male compared to female mortality may represent points or periods in history when men experienced differential higher stress or threats to well-being, for example economic recessions within the context of male dominated economies; much greater male rates of imprisonment due to committing crimes with economic reasons at their origin, and so on.

This paper suggests that sex differences in life expectancy are not just natural differences but that they are also the result of historical societal trends where men and women were differentially protected or stressed compared to each other.

If sex differences in mortality are truly a result of human activities and societal structures (or something else) rather than biology, or interacting with biology, then this inequality in health between men and women can be lessened and what activities would lead to longer healthy lives for men as well as for women.

This study attempts to identify what threats to healthy lives need to be identified to prevent this excess mortality in the future.

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