

Title Page

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Abstract and additional information

ABSTRACT

BACKGROUND: 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 1933 to 2010, and for each year of age from 0 to 60 years, for the USA, and a number of other countries for comparison. The data were explored visually using shaded contour plots.

RESULTS: Gender differences in excess mortality have increased. 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 mortality risks at various ages 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 physiological 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-is~~ not to be inevitable, and in peace time ~~it~~ 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 (1–9). Male infant mortality rates are thought to have always been higher than female infant mortality rates (5), but—~~until childbirth became safer~~—~~more women than men usually died in their twenties and perhaps earlier~~ (10).

Reaching adulthood ~~and means~~ leaving the protection (or confines) of parents or carers, ~~and this~~ leads to a jump in mortality risk for both males and females; however, the spike is noticeably higher for males than females (11,12). Historically, and throughout the world, women of child-rearing age had higher mortality rates than males due to maternal mortality risks (10). ~~Although maternal mortality remains a major, if declining, killer worldwide, there are~~ ~~Now now there are~~ only a handful of countries, where antenatal care is lacking (13), ~~where women die, on average, earlier than men,~~ ~~but maternal mortality remains a major, if declining, killer worldwide~~. If long-term trends are ignored it is easy to think that sex differences are inherently physiological, and that little can be done. This paper challenges this view, by showing how age-specific mortality differences have varied markedly over time and across nations.

Other recent work has referred to these differences and some attempts have been made to explain them. For example, research published in 2013 reported 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; the research concludes that these differences are not natural differences but that they result from socioeconomic conditions that could ameliorated (14).

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 (15).

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 (16,17) 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 indefinitely. Recent work by Luy and Wegner-Siegmundt suggests that the smoking attributable part of the gender gap in life expectancy is very heterogeneous (18).

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 (19); this is in spite of higher mortality rates among men at most points across the life course.

The changing nature of sex differences in age-specific mortality risks, ultimately affecting life expectancies, is rarely discussed among health inequalities researchers; this may be because it has not been considered to be an inequality resulting from unfair practices or processes. It is known that a difference in life expectancy is the result of differences in mortality risks at each age; two very different profiles of age-specific mortality risk could result in identical life expectancies, and conversely a large gap in life expectancy could result from age-specific mortality risk profiles that are identical except over a small range of ages. This suggests that, in order to understand the causes of overall differences, a large amount of disaggregated data will need to be explored.

We wanted to find out whether shaded contour maps, a recently rediscovered method for visualizing Lexis surfaces, could illuminate the issue by allowing large amounts of data to be presented and explored at a glance (20): is there evidence that this is a physiological 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 (21–23). The Lexis surfaces were visualised as shaded contour maps as described in Minton, Vanderbloemen and Dorling (11), and Minton (12). 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. In this paper, each contour shows the excess mortality per 10,000, labelled in increments of 5.

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 blue if the ratios are below 1, indicating a higher female than male mortality rate, and coloured red if the ratios are above 1, indicating higher rates of male than female mortality (online this article is in colour). 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 blue as $5/4$ is dark but red.

Before being re-discovered by Minton and colleagues (11,12) they were used extensively by Vaupel and colleagues in the late 1980s and early 1990s (24,20). The origins of using either shading or contours to visualise demographic data are much older (25,26). All calculations were performed using the statistical programming language R. (Version 3.1.0). The Lattice package (27) was used to produce the contour plots.

Results

The Lexis surfaces of mortality rate differences in the USA, over 77 years in calendar time (1933 to 2010) and over each age in years from newborns to 60 years, is shown in Figure 1. If mortality rate differences were constant over time and at all ages, then the Lexis surface would have a uniform shade, but it does not. If only age influenced these differences in mortality rates, then the contour

lines over the surface would all be horizontal, but they are not. And if the period effects, such as the Second World War, were the only factors needed to explain mortality rate differences, then the contour lines would all be vertical, but they are not. Instead, what the figure reveals is more complex. We can begin by looking at male excess mortality rates in the early twenties over this period, reading the labels off contour lines which intersect this horizontal band on the surface. In the 1930s the male excess mortality for young adults was around five per ten thousand; during the second world war this excess increased, to around 20 per ten thousand; after the War this excess dropped for a number of years, to below ten per ten thousand; then, from the 1950s onwards, the excess increased again, reaching more than 15 per ten thousand again in the late 1960s and early 1970s, only dropping again to below 10 per ten thousand in the late 1990s, and then only intermittently. For example, we also see a “smoking cloud” (Fig 1,B) 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 1995 (Fig 1,C) has not been commented on before, however, or necessarily observed as clearly as we can see it in these diagrams. Beginning in the 1940s, a mortality difference appears, intensifies and persists across the period of available data (2010) among boys and young men 15-25 years old. Visible as an intensifying red colour across the bottom third of the contour map, it could be imagined as an ‘inflammation band’ and is typical of 15-25 year old men in all 37 countries studied, but notable variations can be observed. It is worth noting that access to cars for younger generally less affluent men increased each decade from 1940 onwards in all these countries; ~~very~~ very few young men could afford to drive a car at the start of the period.

[Figure 1 about here]

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 (Fig 1,D). 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.

[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 ages 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 (Fig 2).

[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. 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, and it has also weakened very recently in Japan. 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 10,000 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 10,000 (30 year old) female deaths. This was not the case for their fathers or grandfathers.

[Figure 4 about here]

The side-by-side contour plots in Figure 4 simplify this comparison by showing the 'map' of England and Wales alongside that of the USA. Excess male mortality in the USA compared to England and Wales, 1993 to 2010, at the points of the red arrows, is higher: the corresponding contour line for the USA is >10 male deaths per 10,000 female deaths while that of England and Wales is <5 excess male deaths per 10,000 female deaths, indicating twice the excess male mortality for young

men in the USA compared to young men in England and Wales.

Discussion

During the period from 1933 to 2010 differences in male versus female mortality risk emerged, most notably relative increases in risk 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 competing hypotheses, 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 birth cohort effects (28). In the contour maps it is usually fairly straightforward to identify cohorts affected at birth, as mortality rates for them are noticeably different to neighbouring contours (29).

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 (16).

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. But at the start of the period many men could not afford cars unless they were older and better paid. 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 (30), and by 2013 the proportion of female deaths among 20-25 year olds due to accidents was 40%, nearly equal to that of young men of the same age (42%) (31). When considering the most recent changes in recent years it might be fruitful to look recent changing in car driving and passenger behaviour among young adults, especially those living in greater numbers in urban areas in Switzerland, Canada and Japan.

A fourth explanation is that AIDS deaths may have contributed to the excess male mortality during the 1980s and early 1990s, when they were more common among men than women (e.g. males accounted for 82.4% of all persons with AIDS during the period from 1993 to 1995). The incidence of deaths among adults with AIDS reached a peak in 1995 and declined dramatically once therapy became available (33).

Fifth, unemployment may also have played a role across the past 80 years in influencing 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 (34,35) 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 (36).

The three leading causes of death among 20-24 year olds in the USA in 2013 were 'accidents,' suicide and homicide (31). Though the proportion of deaths due to accidents for men and women was similar in 2013, both homicide and suicide account for larger proportions of male deaths. Because suicide was linked to unemployment in the Blakeley study (35), this goes some way to explaining why unemployment influences the mortality risk for men more than for women.

Philip Enterline in 1961 showed that the importance of tuberculosis and maternal mortality in sex differences was declining in the USA while that of motor vehicle accidents was increasing. While 'accidents' are still a major killer of young men in the USA, this is currently nearly equally true of young women (31). In the cases of suicide and homicide, the difference is more pronounced for men (homicide in particular—in 2013 homicide accounted for about 18% of all-cause mortality in 20-24 year old men, whereas only about 8% for respective women (37). Wilson and Daly's book 'Homicide' provides documentation of the male-bias for homicide in the US, showing sharp in-

creases in homicide rates from the 1960s onwards. They also suggest explanations for male-homicide sensitivity to the social and economic environment (38) .

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 / physiological’ 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

This paper presents visualisation techniques that allow for identification of potential threats to healthy lives, considering age, period and cohort effects simultaneously, illuminating patterns that may otherwise remain overlooked, and visually summarising a country’s epidemiological history based on multiple parameters. Further research could look more closely at historical trends and disease-specific incidence in any of the 37 countries with available high quality data in order to draw inferences about specific public policy changes and whether these affected one gender more than another. Contour plots for all 37 countries are provided for further exploration in an open online repository: https://github.com/JonMinton/Gender_Mortality_Differences/tree/master/images

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