Death rates at specific life stages mold the sex gap in life expectancy

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Why do women live longer than men? Here, we mine rich lodes of demographic data to reveal that lower female mortality at particular ages is decisive—and that the important ages changed around 1950. Earlier, excess mortality among baby boys was crucial; afterward, the gap largely resulted from elevated mortality among men 60+. Young males bear modest responsibility for the sex gap in life expectancy: Depending on the country and time, their mortality accounts for less than a quarter and often less than a 10th of the gap. Understanding the impact on life expectancy of differences between male and female risks of death by age, over time, and across populations yields insights for research on how the lives of men and women differ.

sex gap | life expectancy | decomposition

Between ages 15 and 40, death rates for men are usually two or three times higher than death rates for women. This disparity has fueled widespread interest in the ratio of male to female death rates over the life course and in why it is exceptionally high for younger adults (1–6). Between ages 15 and 40, however, numbers of deaths are relatively low, so the high ratio of male to female death rates has a modest impact on the gap between female and male life expectancies. The sex difference in life expectancy hinges on differences in mortality risks at the ages when deaths are relatively common (7). Up through the early decades of the 20th century, these ages were at both extremes of life, infancy and old age. Afterward, death mostly struck after age 60. Here, we investigate variation across populations, over time, and over the life course in absolute and relative differences in mortality for men and women. We discuss what insights can be gained by scrutinizing relative risks compared to what can be learned by analyzing absolute risks.

Materials and Methods

We used sex-specific mortality data from the Human Mortality Database (8). We computed absolute and relative differences between male and female probabilities of death over age and over time. We decomposed the sex difference in life expectancy into age-specific contributions by applying a stepwise replacement discrete age-decomposition method (9). We also decomposed the change over time in the sex gap in life expectancy. More detailed information about data and methods is reported in *SI Appendix*.

For simplicity, the next section reports only results for the United States, Japan, Russia, and Sweden; results for other populations are included in *SI Appendix*. We highlighted the four countries because Japan is the world longevity leader; the United States struggles to keep up with the survival improvements of other high-income countries; Sweden, the gold standard for demographic data quality, has serviceable records of mortality back to 1751; Russia suffered mortality stagnation and deterioration during the transition from socialism to a market economy, recently seeing improvements in life expectancy.

Results

Age Patterns of Sex Differences in Probabilities of Death. Age patterns of male/female mortality ratios radically differ from age patterns of male–female mortality differences. The ratios at older ages decline toward zero, with modest declines in the smaller ratios in 1900 and stronger declines in the larger ratios in 1960 and today (Fig. 1 *A* and *B* and *SI Appendix*, Fig. S1). The differences at older ages increase (Fig. 1*C* and *SI Appendix*, Fig. S2*F*). True since 1900 for all the countries and regions we studied, this is a fundamental finding about age trajectories of male vs. female mortality: Ratios of male to female death rates decline at older ages, whereas differences increase.

Male/female mortality ratios currently show a peak around age 20 or 25 and often a second peak roughly around age 70. In the countries and regions we studied, the peak of excess male mortality risks at young adult ages tended to be lower half a century ago (Fig. 1*B* and *SI Appendix*, Fig. S1*B*) and of minor importance or nonexistent in 1900 and earlier (Fig. 1*B* and *SI Appendix*, Fig. S1*C*). Currently in Japan excess mortality peaks at a higher level at age 70 than at age 20 (Fig. 1*A*). Strong second peaks around age 70 also occur in recent years in other, but not all, countries (*SI Appendix*, Fig. S1*A*). During most of the 20th century, the mortality ratio rose for most ages and in most high-income countries (10).

After emerging in many countries during the 20th century, the second peak tended to shift to older ages (*SI Appendix*, Fig. S1 *A*–*C*) (11). It tended to decline in recent decades with the reduction of the sex gap in life expectancy, due to convergence of the prevalence of smoking for men and women (12, 13). While in some countries the second peak is still pronounced (for example, Japan, Spain, and France), in others the peak has become less pronounced or negligible (for example, in Sweden and the United States) (Fig. 1*A* and *SI Appendix*, Fig. S1*A*). In Belarus, Russia, and Ukraine, the sex ratio is roughly constant between ages 25 and 65, reflecting high male mortality at young adult ages that continues to middle ages (14).

Excess male mortality at young adult ages differs from country to country. Currently in Japan, young adult men suffer risks of death that are twice as high as those for women; in Sweden and in the

Significance

Female life expectancy exceeds male life expectancy. Males at ages 15 to 40 die at rates that are often three times female levels, but this excess mortality is not the main cause of the life expectancy gap. Few deaths occur at younger adult ages compared with mortality after age 60 or, historically, among newborns. Our demographic analysis shows that, up through the early decades of the 20th century, the life expectancy gap largely resulted from excess deaths of infant boys. Afterward, higher mortality among men 60+ became crucial. The higher mortality of males at ages 15 to 40 has played a modest role.

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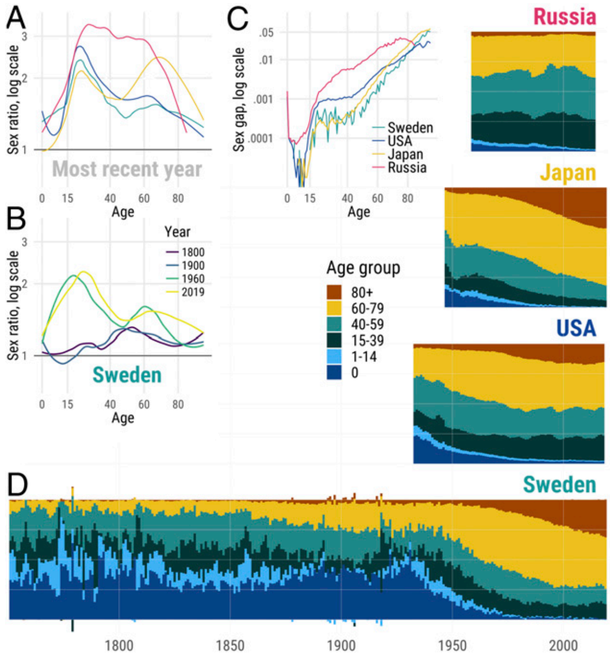

Fig. 1. (*A*) Ratio of male-to-female probability of death in the most recent available year for Russia (2014), Japan (2019), United States (2018), and Sweden (2019). (*B*) Ratio of male-to-female probability of death in Sweden in different years (smoothed). (*C*) Difference of male–female probability of death (on log scale) in the most recent year. (*D*) Relative age-specific contribution over time to the gender gap in life expectancy in Russia, Japan, United States, and Sweden. For a few years, the lowest value is less than zero and the highest value correspondingly greater than 1. In these years, female mortality in one of the age classes exceeded male mortality, reducing the life expectancy gap. Data are from the Human Mortality Database (8).

United States, the risk is higher than in Japan but lower than in Russia, where the risk is more than three times as high (Fig. 1*A*).

The difference in life expectancy between males and females is determined not by ratios of male to female mortality over age but by absolute differences in death rates at the ages when death rates are high and deaths are common (15). Absolute differences in male minus female mortality are high in infancy, decline until about age 10, and then rise with age (Fig. 1*C* and *SI Appendix*, Fig. S2).

Age Decomposition of the Sex Gap in Life Expectancy. Elevated male mortality between 15 and 40 accounts, depending on the country and time, for less than 25% of the life expectancy gap, and less than 10% for Japan and Sweden in recent decades (Fig. 1*D* and *SI Appendix*, Fig. S3). In Sweden in 1751 the contribution of excess male deaths between 15 and 40 accounted for less than 25% the gap. So not only today but also historically, young men accounted for a modest part of the overall female longevity advantage.

The difference in the probability of death between ages 15 and 40 for males vs. females has been roughly constant over time (Fig. 2*C*), albeit with sharp swings before 1920 and with a higher level in Russia. This is consistent with the fairly steady level of the absolute contribution at ages 15 to 40 of excess male mortality to the sex gap in life expectancy (Fig. 2*D* and *SI Appendix*, Fig. S4). For some countries both today and in the past, e.g., Sweden and Japan (Figs. 1*D* and 2*D*), high death rates for men at ages 15 to 40 account for a less than a year of the life expectancy gap. For other countries, e.g., the United States, the contribution has hovered around 1 y. For Russia, Belarus, Ukraine, and Estonia (Fig. 2*D* and *SI Appendix*, Fig. S4), excess mortality for young men has played a bigger role, accounting for more than 2 y of the gap in past decades with some decline recently (16, 17).

Since 1950 high male mortality after age 60 has largely determined the life expectancy gap (Fig. 1*D* and *SI Appendix*, Fig. S3). The importance of older ages has grown in the countries we studied. Men 60+ now account for about 80% of the life expectancy gap in Japan, about 70% in Sweden, and a bit more than half in the United States (Fig. 1*D*). Notable exceptions are Russia and Ukraine, where ages 60+ account for about 40% of the total gap. The contribution of elevated male mortality after age 80 in Japan, Sweden, and various other countries is now greater than the contribution of ages 15 to 40 (Fig. 1*D* and *SI Appendix*, Fig. S3).

Data for the first half of the 20th century and earlier (Fig. 1*D* and *SI Appendix*, Fig. S3) show the significance of high male infant mortality on the life expectancy gap. Indeed, in several countries—e.g., France until 1900, Denmark until 1940—excess deaths of male infants accounted for more than half of the gap. Underreporting of female deaths in the first days of life might explain part of this relationship, but it is clear that before 1900 infant mortality was of great importance in determining life expectancy and the life expectancy gap. Studies of famines and epidemics confirm that when conditions are harsh baby boys die more often than baby girls (18).

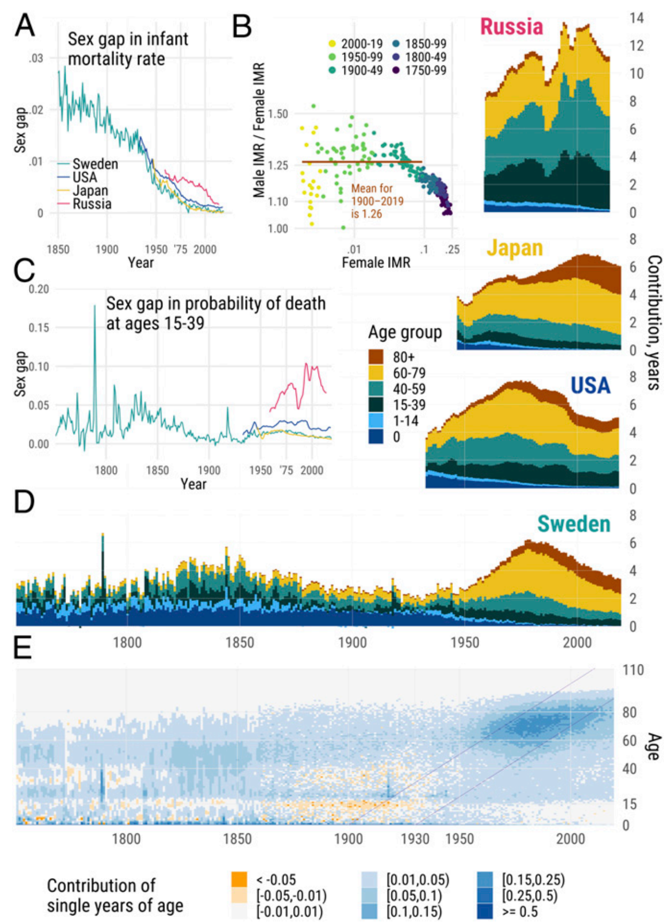

Fig. 2. (*A*) Sex difference in infant mortality rate (IMR) over time for Sweden, United States, Japan, and Russia. (*B*) Ratio for Sweden of male-to-female infant mortality rate (IMR) by level of female infant mortality rate. (*C*) Sex difference in mortality at ages 15 to 40 over time. (*D*) Absolute age-specific contributions to sex gap in life expectancy over time in Russia, Japan, United States, and Sweden. (*E*) Absolute contributions by single year of age to sex gap in life expectancy in Sweden, with diagonal lines marking the cohorts born in 1900 and 1930. Data are from the Human Mortality Database (8).

The large difference between male and female infant mortality rates in the 19th century almost vanished in recent years (Fig. 2*A*) as infant mortality decreased to low levels. Today in the countries we studied, baby boys suffer somewhat higher mortality than baby girls, but the difference is small, and the levels of infant mortality are so low that contributions to the absolute gap are negligible. In sharp contrast to the decline of the absolute male–female gap, male infant mortality rates relative to female levels rose from 1751 through 1900 (19) and afterward reached a plateau at roughly 1.25 (Fig. 2*B*). Around the world, girls usually suffer lower mortality than boys, but exceptions exist, which might be due to differential treatment (20, 21).

Additional Findings. The life expectancy gap peaked about the end of the 1970s in the United States, about 1980 in Sweden, and a quarter of a century later in Japan and Russia (Fig. 2*D*) with the gap in other countries also attaining maximums late in the 20th century or very early in the 21st century (*SI Appendix*, Fig. S4). The gap reached 6 to 8 y in United Sates, Sweden, and Japan and other countries, but much higher levels of 12 to 14 y in Russia, Belarus, Ukraine, and Estonia (Fig. 2*D* and *SI Appendix*, Fig. S4). The gap has declined substantially from its peak in almost all the countries we studied. The decline since the peak resulted from changes from positive to negative absolute age-specific contributions at ages under 60 in Eastern Europe and under 80 elsewhere (*SI Appendix*, Fig. S6). Absolute contributions to the life expectancy gap generally increased after age 80, reflecting the growing importance of the oldest ages in determining the sex gap in life expectancy (22).

The increase and decrease in the gap were largely due to the smoking epidemic (12, 13, 23, 24). The smoking epidemic is the likely cause of the blotch of excess male mortality in Sweden between ages 60 and 80 for cohorts born between 1900 and 1930 (Fig. 2*E*). A similar blotch can be seen in the United States for cohorts born about a decade earlier and for other countries for cohorts born a decade or two later (*SI Appendix*, Fig. S5). Young men can be blamed for starting to smoke, with deadly consequences at older ages, but older men can be faulted for not stopping: It is difficult to untangle the interacting contributions of age-specific behaviors and environmental conditions (25).

Fig. 2*E* reveals that in Sweden before 1950 at some ages and times women suffered higher mortality than males (the yellow areas) or closely similar mortality (the white areas). Because of this, the overall contribution of excess male mortality between ages 1 and 15 is small and can hardly be discerned in Fig. 2*D* and similar graphs for other countries in *SI Appendix*, Fig. S4. Up until 1930 or so, female mortality often exceeded male levels in childhood and up to about age 40 (Fig. 2*E* and *SI Appendix*, Fig. S5). This is not surprising, as, historically, females have been disadvantaged because of the burden of high levels of maternal depletion (26, 27), discrimination in intrahousehold resource allocation, both during childhood and at adult ages (28–30), and excess mortality from tuberculosis (31).

Conclusion. How and why the life experiences of men and women differ is a topic of endless speculation that can fruitfully be viewed through the lens of demography. Reliable population data on mortality for males and females by age is a resource over centuries of time and for many populations. These data reveal that before 1950 the excess mortality of baby boys was the biggest contributor to the sex gap in life expectancy, suggesting a strong biological underpinning of mortality at an age when the behavior of boys and girls is similar and when, in some settings, parents might favor boys (28–30). More recently, high mortality among men 60+ has played the key role. The behavior of young men, who, for example, take up cigarette smoking, undoubtedly impacts their health as they grow older. Except, however, for people born between about 1900 and 1930, with heavy male smoking, strong patterns of high male mortality by birth cohort are not apparent in the figures.

The sex gap in life expectancy appears to be rooted in biological differences between males and females, modulated by social norms, constraints, incentives, roles, and epidemiological contexts that permit behavioral and environmental differences that affect health. To better target health policy, deeper understanding is needed of the intricate interplay of physiology and culture in determining male–female differences. Analysis of differences in death rates by age, over time, and across populations opens a window for research on why the lives of men and women differ.

Data and Materials Availability. The age-specific contributions to sex gap in life expectancy have been deposited in Zenodo (https://doi.org/10.5281/zenodo.4609344) (32). All data used for the analysis are available online from the Human Mortality Database (https://www.mortality.org/hmd/zip/all_hmd/hmd_statistics.zip). The R code to replicate all the calculations and figures is openly available at Zenodo, https://doi.org/10.5281/zenodo.4609344, and GitHub, https://github.com/CPop-SDU/sex-gap-e0-pnas.

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