The sex differential in mortality:
A historical comparison of the adult-age
pattern of the ratio and the difference

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Abstract

The ratio (RMR) is the standard measure of sex differentials in mortality. It is commonly known that the RMR was historically small and increased throughout the 20th century. However, numerical properties might account for the trend in the RMR rather than sex differences in risk factors. In this study we examine the age pattern of the absolute difference in male to female mortality rates (DMR) as an alternative measure in a historical context and compare it to the RMR pattern. Whereas the RMR is close to one at every age in the 19th and early 20th century and increases until the present day, the adult age pattern of the DMR is relatively stable throughout the last 150 years. We also found that the DMR is approximately exponentially increasing from age 40 to 90, implying a universal biological force behind sex differentials in mortality. However, interactions between biology, behavior and environment are complicated and have to be considered when interpreting these findings. Moreover, between ages 15 and 40 the DMR declined in the second half of the 20th century, whereas the RMR increased. Hence, the trend in the latter measure is likely to be an artifact of very different mortality regimes between populations. Therefore, we argue that it is necessary to consider both measures when conducting comparative analyses and to be careful in interpreting their time, cross-cultural and age trends, since they can lead to different conclusion about sex specific underlying risk factors.

Introduction

Sex differentials in mortality
It is well documented that in all human populations for which respective vitality data exist male death rates exceed that of females at virtually every single age year. In contemporary developed countries, the male disadvantage is universal throughout the whole lifespan, whereas in various historical and developing countries a female disadvantage is reported especially during childbearing years. The disparity in life expectancy between the sexes has been growing throughout the 20th century. This diverging trend can partly be explained by the declining rates in maternal mortality. However, a major element is attributable to sex differences in behavior and biology. Due to these differences, males and females respond differently to changing environments in the outcome of mortality. For instance, primary care, specialty care, emergency treatment, diagnostic services, and annual total charges are all significantly higher for women, whereas mortality is higher in men (Bertakis et al. 2000). It has been found that this is most likely due to a higher incidence rate of non-fatal diseases in women and fatal diseases in men, like cardiovascular diseases, rather than better self-assessment of signs of diseases in women (Case and Paxon 2005). Hence, biological and behavioral factors, which account for a higher rate of fatal diseases among men, in combination with improving health care systems affect the diverging sex gap. In former East-Bloc countries, behavioral risk factors alone account for extensively high excess male mortality. For example, 15 year old Russian males faced a 12.6 year lower life expectancy than females in 2000-09. This is extraordinary high compared to western developed countries (e.g., Germany: 5 years) and had been attributed to an uncommonly high alcohol and tobacco consumption rate among Russian males (McCartney et al. 2010). In general, premature deaths due to risky male behavioral patterns are universal and related to higher rates of homicide (Gartner et al. 1990), suicide (Möller-Leimkühler 2003), drug abuse (Rehm et al. 2006) and traffic accidents (Wilson and Daly 1985).

Biological sex differences account for some part of this sex gap, but are assumed to be small and temporarily invariant. In contrast, behavioral patterns and environmental conditions are suggested as primary causes for variations in the sex gap between populations (Rogers et al. 2010, Seifarth 2012). However, the specific determinants and interaction effects of all factors remain unclear (Rogers 2010, Nathanson 1984). In terms of the diverging sex gap, it had been suggested that the widespread introduction of cigarettes, which was socially more accepted and common among males in the first half of the 20th century, contributed to higher rates of cardiovascular diseases among men and is therefore an important factor for explaining the increase in the sex differential in life expectancy (Waldron 1985). Since the 1980s the gender gap in life expectancy started to converge in westernized countries due to the late effects of increased tobacco consumption among women (Pampel 2003). Actually, smoking accounts for 40-80% of the sex gap in European countries (McCartney 2011).

Since behavioral risk patterns show variation over age -a prominent example is the immense drop in traffic accident rates between young adults versus middle age adults (e.g., Wilson and Daly 1985)-, an age specific measure of sex mortality differentials is useful to highlight certain age groups in which males are exposed to an unusually high risk. This information is important for developing strategies of health and risk prevention and to understand how environmental or social conditions trigger excess male mortality. Even though cause specific mortality data would be ideal to identify

sex and age specific differentials in risk factors, this information is often not available or reliable especially for historical data and developing countries. Moreover, cause specific data may be biased by several factors reducing the reliability of death certificates (e.g., Modelmog et al. 1992). The most commonly used method in measuring sex differentials over age in either cause specific or all-cause mortality is the ratio.

The sex mortality rate ratio in a historical context
Documentations of the ratio in male to female mortality rates (RMR) can be traced back to a long tradition of studies of the sex gap. One of the pioneers who reported on increasing age specific RMR in the early 20th century was Dorothy Wiehl (1938). She first mentioned a diverging sex gap in the 20th century by means of the ratio in mortality rates. Her findings inspired demographers to focus attention on this topic. In the following decade the ratio had been established as the preferred age specific measure for sex mortality differentials. Yerushalmy (1943), for instance, studied the age pattern of the RMR. He reported that the relative mortality risk between males and females is highest around ages 20 and 60. This 'two humps'-pattern of the RMR is universal in westernized countries in the 20th century, but rare in 19th century Europe (Glei 2005). Based on the first descriptive analyses, researchers focused their attention on the underlying determinants of the diverging sex gap by analyzing the RMR for different subpopulations and causes of death.

For example, Martin (1951) conducted an extensive analysis of the RMR in European countries between the 1870s and the 1940s to identify determinants of the evolving sex gap. He analyzed the ratio of male to female cause, social class and occupation specific death rates. He found that occupational risk was the main driver in young male mortality in the second half of the 19th century, especially for industrial workers. With the beginning of the 20th century safety permanently increased in hazardous working environments which mainly affected young workers, who did most of the manual work. This fact puzzles Martin, since the RMR increased, especially at younger ages. He tried to explain this paradox with rapidly declining maternal mortality. However, even though maternal mortality dropped rapidly, it might not explain the increase of the RMR throughout the 20th century. Moreover, maternal mortality did not substantially decline anymore in Western European countries after the 1960s (De Brouwere et al. 1998) and cannot explain the increasing RMR at young adult ages throughout the last century. Martin (1951) also found that a very high RMR appears in the highest social class, whereas it was lowest in the poorest class. This is paradox when considering that in the lowest class males had been exposed to more hazardous work. Irwin added an interesting explanation of these paradoxes in the discussion attached to Martin's article. By considering that the RMR is inversely related to the denominator, the observed phenomenon may be explained, at least in part, by declining mortality rates in the westernized world. Furthermore, it may explain higher RMR in high social classes, since higher classes experience lower mortality rates compared to lower classes. Even though this is a reasonable alternative explanation of the observed trend, Irwin's objections have been mostly ignored in ensuing analyses of the sex differential by means of the mortality rate ratio. The numerical problem appears to be always when sex differentials in mortality between populations are compared, which differ in their mortality regime. This is also a problem when comparing different age groups within the population. Differences in the RMR may always be affected by differences in mortality levels and, hence, information about differences in sex specific risk factors can be distorted.

In other fields of research, the different implications of absolute and relative measures had been a topic of great importance. For example, Moser et al. (2007) showed that both measures can lead to different conclusions about health inequalities across countries and times. The authors found that for some countries the time change of health inequalities was either positive or negative depending on the measure. In medical studies it has been argued, that an absolute measure between control and treatment group is more useful in rational decision-making of medical treatment in clinical practice (Tramer 2005).

Even though the methodological problem was mentioned 60 years ago and is debated in epidemiological and clinical studies, the age pattern of total or cause-specific mortality rates by means of the ratio in a historical or cross-cultural context is still the preferred method in recent studies of the sex gap (e.g., Glei 2005, Gjonça, 2005, Kalben 2000, Kostaki, 2011, Sorenson 2011, Yang and Kozloski 2012, Westerling 2003).

The reasons for the unawareness of the numerical problem of the RMR might be manifold. One likely explanation is that the widening of the sex difference in life expectancy throughout the 20th century perfectly fits into the observation of increasing RMR's. However, Glei (2005) found that the declining sex gap in life expectancy since the 1980s does not fit into the pattern of the RMR in westernized countries. This is not entirely surprising, since the sex difference in life expectancy is not necessarily proportional to the RMR (Pollard 1982, 1988). Another reason for the uncritical interpretation and acceptance of the RMR might be that it is a simple comprehensible measure which can be easily communicated to a broader public.

The age pattern of the absolute sex difference in mortality rates
An alternative measure to the RMR is the difference between male and female mortality rates (DMR). This measure, however, is uncommon among demographers and only a few studies report on it. For instance, Stolnitz (1956) studied the general shape of sex differences in age specific survival probabilities, which is equal to the negative of the sex difference in the probability of dying. Western populations between 1920 and 1950 show a bathtub-shaped pattern of the difference; the curve declined from age 0 to age 1 and increased slowly until age 40 and then more rapidly until the oldest age (Stolnitz 1956). This is in accordance with the age pattern of RMR found in the US population in 1910, 1965 (Retherford 1975) and 1980 (Wingard 1984). But what was the pattern in the 19th century when the sex gap in life expectancy was relatively small and how is it nowadays in contemporary countries? Did the DMR always increase over age or is its age pattern time variant like for the RMR? These questions cannot be answered, since no comprehensive analysis of the DMR exists so far.

Aims of this study
A comprehensive study of the age pattern of the DMR is more than overdue. It is not known how the age pattern of the DMR behaves in a historical context. In contrast, the RMR had been extensively studied. It is well known, that its age pattern is very flat and close to one in historical populations and increased throughout the last century. However, this increase may partly be due to a substantial drop in overall mortality levels since the late 19th century and, hence, might not only reflect changes in sex specific risk factors. If both sexes equally benefit from some reductions of risk factors which lead to declining mortality rates over time, this would be reflected by an increase of the RMR. The DMR, on the other hand, is not affected by reductions in

overall mortality levels. Moreover, the sex difference in life expectancy, the 'currency' of the sex gap, is only poorly related to age specific contributions of the RMR. In contrast, the relation between the DMR and sex differences in life expectancy is much stronger and approximately proportional (Pollard 1982, 1988). This study aims to analyze the age pattern of male versus female mortality rates in a historical context and compare it to the trend of the male versus female mortality rate ratio to fill in the gap of this underrated topic. For this purpose, we will analyze the age pattern of the DMR and its historical changes throughout the past 150 years and compare it to the RMR patterns. Since this study is mainly descriptive, we will only briefly discuss determinants of the observed age patterns. Moreover, we focus on adult ages and discuss possible applications in future research.

Data and Methods

Age and sex specific, decade-wise death counts ($D(x)$) and person years lived ($E(x)$) from the Human Mortality Database (HMD, 2014) were used to calculate age and sex specific mortality rates ($\mu_M(x)$, $\mu_F(x)$) as

(1) $\qquad \mu_{M,F}(x) = \dfrac{D_{M,F}(x)}{E_{M,F}(x)}$

The absolute difference of mortality rates, *DMR(x)*, is calculated as

(2) $\qquad DMR(x) = \mu_M(x) - \mu_F(x)$

and the ratio in mortality rates, *RMR(x)*, by

(3) $\qquad RMR(x) = \dfrac{\mu_M(x)}{\mu_F(x)}.$

We calculated the *DMR* and the *RMR* for three European countries (Sweden, France, England & Wales) in five decades (1860-9, 1900-9, 1950-9, 1980-9 and 2000-9) for single age years from 15 to 90. The decade-wise counts of vitality data start at January 1st of the first year and ends at December 31st of the last year of the respective decade.
Even though the HMD provides data up to 110+, we excluded these age groups from our study, since population counts rapidly decline after age 90 especially in historical populations. Observed patterns of the sex differentials at very old age might be more due to statistical perturbations rather than real effects.
All calculations and figures were done using the statistical computing software R (version 3.01) and the integrated development environment software RStudio (version 0.97.551).

Results

The ratio
The age pattern of the ratio in male to female mortality rates (RMR) was very flat in the 1860s and 1900s. Between the 1860s and 1900s the RMR slightly declined in Sweden, whereas in France and England & Wales (E&W) it slightly increased (*Figure 1*). In general, the RMR steadily increased from the 1900s until the 1980s in all three countries. The increase took place over the whole adult lifespan, but was pronounced in two 'humps'; a steep one around age 20 and a flatter one between ages 50 and 70. At the highest age, the ratio tends to decline and converges to one in all decades.

England and Wales shows a slightly divergent time trend in the pattern of the second 'hump' compared to Sweden and France. Between the 1950s and the 1980s the RMR declined between ages 50 and 70, in contrast to the increase in the other countries. From the 1980s to the 2000s the RMR hardly changed in respect to the first 'hump'. After age 40 the decline in the RMR was much more pronounced.
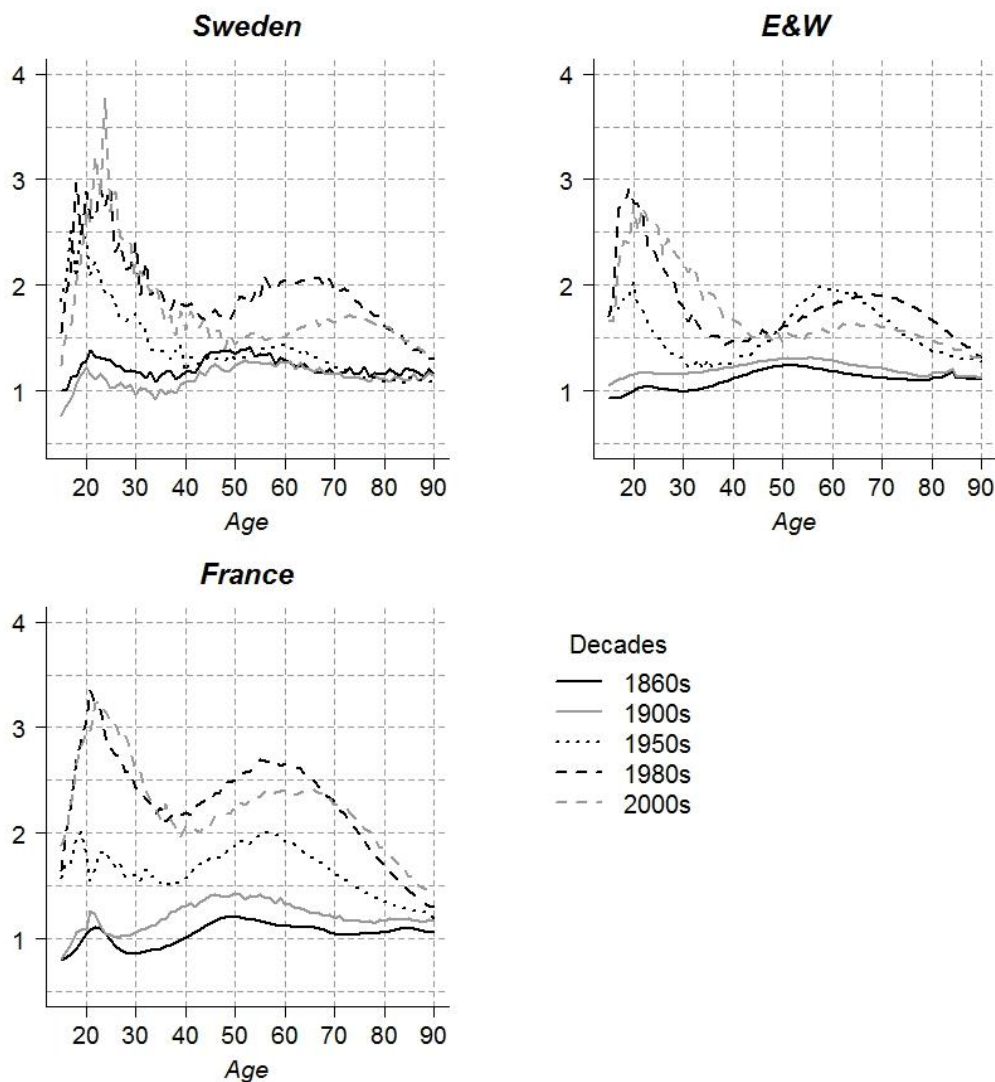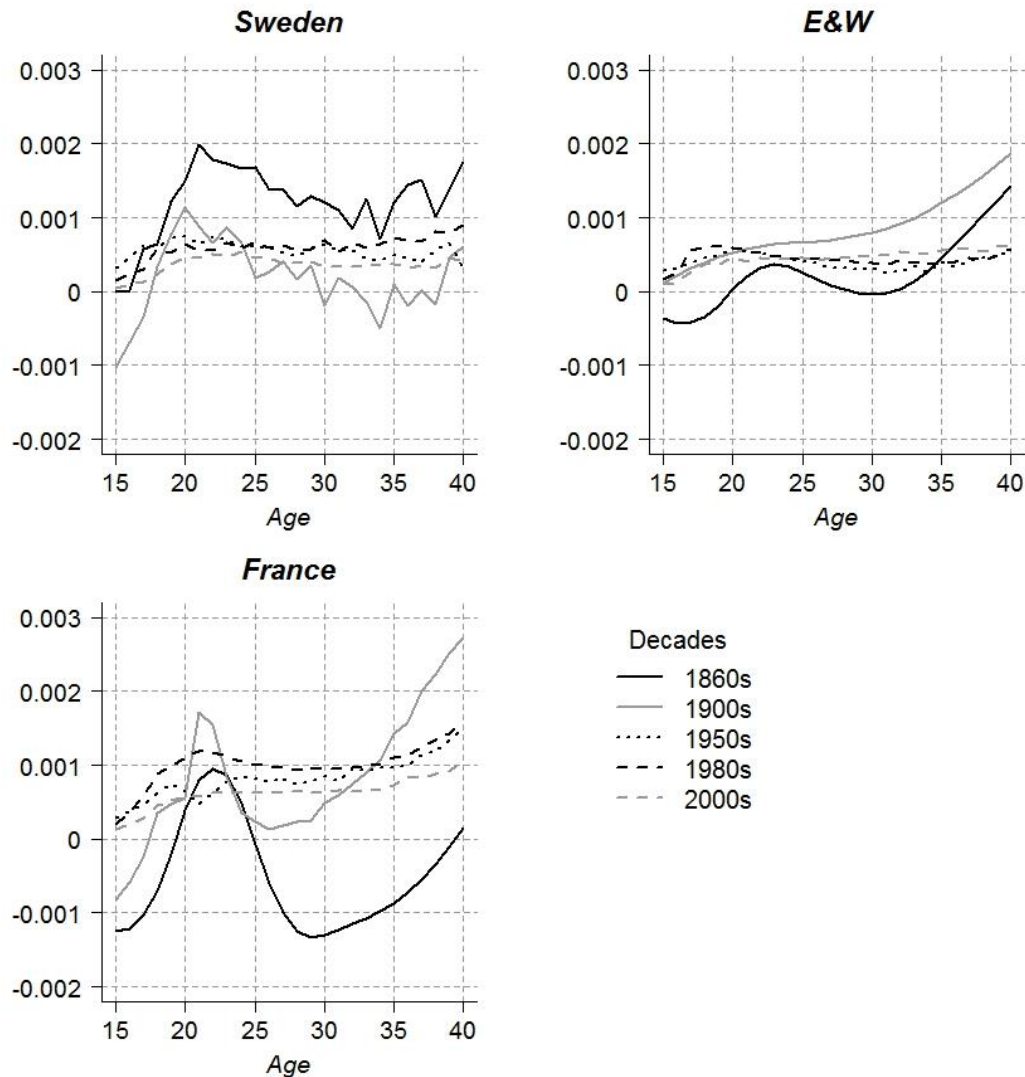

Figure 1. *Male excess mortality by means of the ratio (y-axis) at single age year between 15 and 90 (x-axis) in three European countries.*

The difference between ages 15 and 40
Figure 2 shows the excess male mortality through the difference between ages 15 and 40. Even though the age pattern of the DMR varies over time, the age pattern across countries is quite consistent. In the 1950s, 1980s and 2000s the age pattern was very flat (between 0 and 0.001) with an increasing trend between ages 15 to 20 and very similar in all countries.

Figure 2. Male excess mortality by means of the difference (y-axis) at single age year between 15 and 40 (x-axis) in three European countries.

In the 1860s and 1900s the age pattern of the DMR reveals an increase of male excess mortality with a peak roughly around age 20, then declines until age 30 when it starts to increase again. The level of the RMR differs, whereas the age pattern is generally similar, even though it is differently realized among the three countries.

In Sweden, the difference was relatively high in the 1860s compared to the other decades and peaked at age 21 with a value of 0.002. In the 1900s, the shape of the age pattern of the difference was similar to that in the 1860s, but in parallel had shifted downwards by approximately 0.001.

In France and England and Wales the difference increased from 1860s to 1900s. In 1860s France, female mortality exceeded that of males in every single age year except

for ages 19 to 25. Around these ages, the DMR is characterized by a peak with a maximum around 0.001 at age 22. From the 1860s to 1900s the DMR shifted upwards, with the lowest change around younger ages (0 to 0.0025). However, the general age pattern was entirely preserved.

In 1860s England and Wales, the difference showed a similar shape compared to France, but with a less pronounced and lower peak at age 23 (0.00037). In the 1900s the hump-shape was almost smoothed out and the difference was higher at each single age year compared to the 1860s.

Throughout the second half of the 20th century the level of the DMR hardly changed. The only evident change is that, there is a slightly declining trend in Sweden and France, whereas in England and Wales the DMR is relatively constant in the three latest decades.

The difference between ages 40 and 90

Figure 3 shows excess male mortality by means of the difference between ages 40 and 90. The semi-logarithmic scale was chosen to highlight differences between the decades, which is not possible to such an extent on an arithmetic scale. First of all, the DMR ranges by a factor of 100 over the whole age range, showing an approximately exponential increasing trend in all three countries and all decades. Historically, there are, however, slight differences in the age pattern of the DMR, but these trends are, as for the young age pattern, fairly similar across countries.

For the decades 1950-9, 1980-9 and 2000-9 the age pattern is almost a straight line on a semi-logarithmic scale. There is however a tendency of a bending off at high age. This is most extreme in England &Wales where the bending off starts earlier than in any other country.

The straight-line pattern of the DMR at middle to adult ages cannot be found in any country prior to the 1950s. Even though the DMR is increasing over age in the decades 1860-9 and 1900-9, its age pattern is characterized by an inversed s-shape. However, in 1860s France the age pattern of the DMR was very erratic. Even though the curve is clearly increasing, it does not show an exponential or inversed s-shape pattern. Moreover, the increase of the DMR over age is disrupted by declining trends for ages 65 to 72 and after age 85. In the 1900s France, the DMR was much smoother over age characterized by an inverted s-shape as reported for the other countries.

From the 1860s to the 1900s the DMR dropped approximately parallelly in Sweden, whereas it increased in England & Wales and France. The shift in England & Wales is not entirely parallel, but the inverted s-shape pattern remains. Moreover, a unique peak of the DMR in England & Wales appears at age 84. This is due to data issues. Annual numbers of deaths and population counts were summarized in the open age interval 85+ in the original tables. To get single age year estimates, deaths and exposures for age above 84 had been calculated by the Kannisto-model for old age mortality (Thatcher et al. 1998). For further information see the method protocol for the HMD by Wilmoth et al. (2007).

In 1950s Sweden, the DMR also shows an inverted s-shape over age in contrast to the other countries. Moreover, at ages above 55, the DMR in Sweden is even similar to that in the 1900s.

Whereas the shape of the age specific DMR pattern is very equal in all countries from the 1950s to the 2000s, its temporal change differs between the countries. In Sweden, the DMR increases from the 1950s to the 1980s at each age. In contrast, in England & Wales the DMR slightly declined from the 1950s to the 1980s between ages 40 and 70, but slightly increased at higher ages. There is no change in the level of the DMR

between 1950s and 1980s France. After the 1980s all countries show a rapid substantial decline of the DMR.
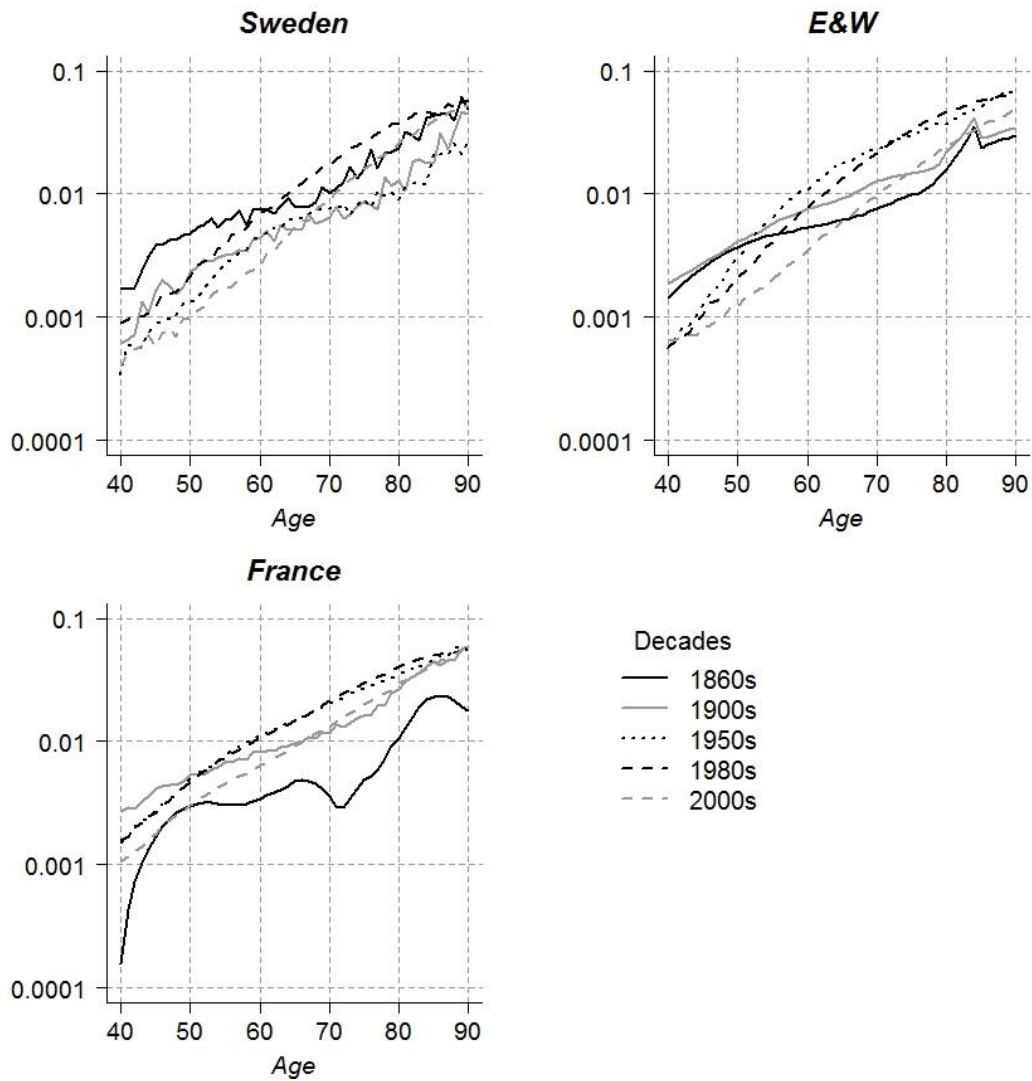

Figure 3. Male excess mortality by means of the difference (y-axis) at single age years between 40 and 90 (x-axis) on a semi-logarithmic scale in three European countries.

Discussion

The age pattern of the sex differential by means of the ratio substantially differs from that by means of the difference. The most striking finding is that the DMR increases from middle to old age (40 to 90) in all decades and countries in the study. Moreover, in the three last decades the curve of the DMR is clearly exponentially increasing and bends off at old age, except for 1950s Sweden. The bending off may be explained by selection processes. Since males suffer from higher mortality, the proportion of frailer individuals declines faster in the male population compared to in the female population. The increase in the DMR is slowed down at higher ages. Such effects "may be a factor in observed declines and reversals with age of mortality differentials between pairs of population" (Vaupel et al. 1979, p.440). The explanation for the exponential increase is, however, more challenging. In the 19th and early 20th century the age pattern of the DMR describes an inverse s-shape curve rather than a straight line. Hence, two DMR-specific curve-types can be found in all three countries in the study. The irregular pattern in 1860s France is due to a cohort effect (see Figure 4). As shown in Figure 4, the cohort effect traces back to the 1770s and 1790s birth cohorts. This is a rare and remarkable example of female excess mortality throughout major parts of the adult lifespan. This pattern might be linked to the devastating crop failure and famine in 1788-89 and the following French revolution. The years around the 1770s are also characterized by riots due to food shortages. However, shocks, such as malnutrition in fetuses or early infancy, are only weakly related to mortality in adult life (Roseboom et al. 2001, Myrskylä 2010) and a female disadvantage in late life due to famines had not been reported so far. An alternative explanation might be that the early shocks led to stronger selection among males due to higher infant mortality compared to females. However, these are only speculations and so far there is no explanation for the excess female mortality in the 1770s and 1790s cohorts in France. Therefore, this observation needs further examination in future studies. Since the age pattern of DMR at adult ages (40-90) is quite stable over time (except for the special case of France) the underlying mechanism leading to this pattern should be universal. Since sex differences in biological risk factors are assumed to be fixed and invariant over time (Seifarth 2013), this explanation may be a good candidate for driving the age pattern of the DMR. However, biological differences are also assumed to be small between men and women (Rogers et al. 2010) and may not account for a large part of the sex gap in mortality rates. For example, Luy (2003) found that monks and nuns in cloistered populations, which share a similar life style, have a life expectancy gap of approximately one year. The author concluded that this difference is mainly attributed to biological differences. So why is the DMR then low at young age, when external causes are mainly responsible for deaths and high at old ages, when biological aging processes account for a major part of mortality? A possible explanation can be found when considering the complexity of death events. Even though biological sex differences are fixed, environmental and behavioral risk factors can lead to an exaggeration in sex mortality rate differences due to interactions with physiological aging processes. In simpler words, a risky behavior at old age is more likely to be fatal compared to that behavior at a young age. Environmental and behavioral risk factors have more impact on the chance of dying with increasing age due to physiological aging processes. If women behave less riskily, then their probability of mortality increases more slowly from each single age year to the next compared to men. Hence, the mortality gap diverges over age, even though biological differences can be small or even absent. Therefore, the exponential

increase in DMR may be solely attributed to sex differences in behavioral and environmental risk factors. Variations over age in the level or shape of the DMR-curve may be a result of temporal changes of the age pattern of such risk factors. A good example is the rate of fatal traffic accidents per mile driven. The chance of an accident declines from young age to middle age, but after a certain age it starts to increase again until old age and even exceeds that of younger ages (Wilson and Daly 1985). Since this pattern is unlikely to be caused by higher risk taking among the elderly, lower reaction times and higher frailty are possible determinants.

In contrast to the age pattern of the DMR, the RMR is flat in the 1860s and 1900s and two 'hump'-shaped in the three latest decades, as already documented by several other studies. Moreover, the RMR implies that the mortality differential had been growing throughout the 20th century at each specific age. This is, however, not supported by the absolute sex difference in mortality rates. For instance, the DMR in Sweden was much higher in the 1860s between age 17 and age 60 compared to all other decades in the study. In contrast, the RMR in the 1860s was flat and did not exceed the level at any single age in the 1980s and 2000s. Actually, male mortality was generally very high due to alcohol consumption and tuberculosis (Fridlizius 1988) in historical Sweden. Between ages 15-40 the DMR shows a typically 'hump'-shaped pattern in the 1860s and 1900s, whereas the age patterns in later decades are flattened out. The 'hump'-shape is likely linked to maternal mortality. In contrast, the RMR shows a temporarily reversed age pattern. It is flat in the two oldest decades, but 'hump'-shaped in the three latest ones. Additionally, the DMR at young ages tends to decline in two of the three countries (Sweden and France) throughout the 20th century, whereas the ratio clearly increased in all countries. This might be an artifact of declining mortality levels in the population, because the RMR increases with a declining denominator.

The numerical problem is also likely to account for inconsistencies of the relative proportion of changes in the RMR compared to the DMR. For the age group 15-40 the biggest changes in the DMR took place between the 1860s and 1900s, whereas the biggest changes of the RMR in the same age bend took place from the 1900s until the 1980s. The increase of the RMR can, at least in parts, be explained by the rapid drop in mortality rates of both sexes with the beginning of the 20th century rather than by a divergence of sex specific risk factors. Therefore, the ratio has to be handled when interpreting sex differentials in a historical context.

DMR in France, 1816-1900
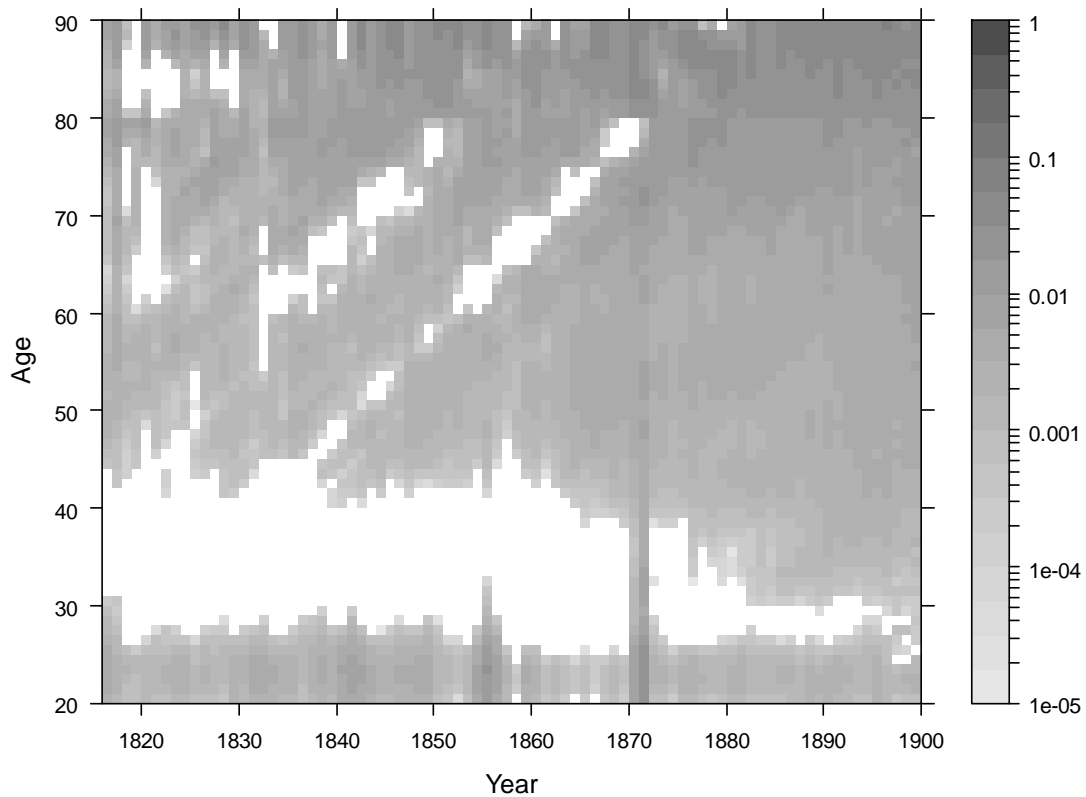
Figure 4. Male excess mortality by means of the difference represented by gray shades over single age years and period years. White areas indicate female excess mortality. Two cohort effects can be identified; one in the 1790s and in the 1770s cohort. Both effects account for an irregular trend of the DMR in the 1860s France.

However, a numerical problem also appears by using the DMR, since excess male mortality cannot exceed female mortality rates. Hence, the exponential increase over age might be a simply due to increasing mortality rates as well as some declining trends over time. For instance, Boback (2002) showed that the mean DMR (ages 35-69) is directly proportional to male and female mortality combined among 32 contemporary countries. However, not all observations of the RMR or DMR may be explained by numerical issues. For example, in France and England & Wales the DMR increased from the 1860s to the 1900s in the age group 15-40, although total mortality declined. The increase must therefore be linked to sex specific risk factors, possibly related to shrinking maternal mortality. The RMR, on the other hand, increases from age 40 to 60 in most westernized countries, even though the denominator also increases. There has to be a clear male risk factor which accounts for this trend. Nevertheless, a measure which corrects for mortality levels in a population allows distinguishing between numerical effects and sex specific risk

factors and provides a promising outlook on future research on the determinants of the sex gap.

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