Original Article

Sexual selection and the Male:Female Mortality Ratio

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Abstract: This paper extends the evolutionary understanding of sex differences in mortality rates by quantifying and graphically examining the overall Male to Female Mortality Ratio (M:F MR) for 11 specific leading causes of death across age groups in the USA, over the course of the lifespan in 20 different countries, and across the past 70 years in 5 countries. The resulting quantitative descriptions of rates, trends, and the relative contributions of various proximate causes of death to the M:F MR provide an initial exploration of the risks associated with being male. This analysis also illustrates how sex differences shaped by sexual selection interact in complex ways with multiple aspects of culture and environment to yield a pattern that has some consistency across decades and societies, but also has variations arising from differences among cohorts and cultures. The results confirmed our expectations of higher mortality rates for men than for women, especially in early adulthood, where three men died for every woman who died. For external causes the ratios were even higher. Historical mortality data reflect an epidemiological transition in which discrepancies between male and female mortality rates increase as general mortality rates fall. Cross-national variation in the modern M:F MR further suggests a universal pattern that is influenced by cultural and environmental context. Being male is now the single largest demographic risk factor for early mortality in developed countries.

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1. Introduction

The discrepancy between male and female mortality rates, recognized since at least 1750 (Kalben, 2000), has been explained by an array of biological and behavioral proximate causes (Hazzard, 1990; Kraemer, 2000). Evolutionary

researchers have described how sex differences in mortality are explained by traits shaped by sexual selection interacting with cultural and environmental factors (e.g., Daly and Wilson, 1985). The integration of evolutionary and proximate models remains rare, however, in studies of mortality. This paper provides an example of how evolutionary and proximate/cultural approaches do not necessarily contradict each other but can together contribute to a coherent comprehensive explanation. The focus here is on the ratio of male to female mortality rates (M:F MR) at different ages for the leading causes of death in the USA, for all causes of death across 20 nations, and across historical time for 5 nations. Together they illustrate the importance of incorporating both evolutionary and proximate/cultural factors into explanations for mortality.

1.1 Sexual selection and longevity

In species where females make a greater parental investment, they tend to be more discriminating in mate choice, so the reproductive success of males depends largely on their ability to compete for mating opportunities (Trivers, 1972) either by winning fights with other males or by presenting displays preferred by females (Darwin, 1871). The fitness benefits of these outcomes tend to increase the prevalence of genes that promote male risk-taking and competitive ability at the expense of decreased investment in repair capacity and disease prevention (Daly and Wilson, 1978). This is the evolutionary reason why females live longer on average in most animal species (Hazzard, 1990). It illustrates how natural and sexual selection tend to maximize the survival of genes, sometimes at the expense of the survival of individuals. A pleiotropic gene that has a beneficial early effect and a detrimental late effect will be selected for because younger individuals have a higher reproductive value. The cumulative result of these pleiotropic genes is senescence (Williams, 1957).

1.2 Physiological and behavioral differences

Compared to women, men tend to have greater height and weight, more upper-body strength, higher metabolic rates, higher juvenile mortality, later sexual maturity, and shorter lifespans (Cronin, 1991). The role of sexual selection is supported by the high correlation between excess male mortality and sexual size dimorphism across mammalian taxa, after controlling for the effects of phylogeny (Promislow, 1992). Some increased risk results directly from the increased vulnerability of male structural, physiological, endocrinological, and immunological systems, especially lower resistance to infection, injury, stress and degenerative diseases (Folstad and Karter, 1992; Hazzard, 1990). Male mammals are also more likely than females to have parasites (Moore, 2002), both because of the immunosuppressive effects of testosterone and because their bodies are simply larger (Folstad and Karter, 1992). Infection or parasites kill twice as many men than women in developed countries,

four times as many in undeveloped countries (Owens, 2002). Hamilton and Zuk (1982) have proposed that females are sensitive to physiological cues reflecting parasite loads in potential male mates, with the exemplar being female birds who prefer brightly colored males. Men are also more susceptible than women to mortality stemming from cold winter months than women are (Rau and Doblhammer, 2003).

1.3 Mortality risk and unhealthy male behaviors

Sexual selection also helps to explain some differences in behavioral tendencies, including risk-taking, competitiveness, and sensitivity to hierarchy (Cronin, 1991). Greater male than female variation in reproductive success means that risk-taking has higher payoffs for males as they compete for resources, social status, and mates (Daly and Wilson, 1985).

Special selection pressures faced by females may also have increased sex differences in the tendency for engaging in risky behaviors. The costs of risk-taking tend to be higher for women because offspring survival depends more on maternal than paternal care and defense (Campbell, 1999). This notion fits quite well with the recent recognition of sex differences in behavioral responses to stress. Rather than the "fight or flight" behavior that may characterize male behavioral reactions to adverse circumstances, the female behavioral pattern is thought to resemble a "tend-and-befriend" response where nurturant tending activities protect and reduce distress in oneself and offspring and safety and befriending activities create and maintain social networks facilitating this process (Taylor, Klein, Lewis, Gruenewald, Gurung, Updegraff, 2000).

The tendency for males to be less cautious is thought to account for much of the sex difference in rates of violence and the use of alcohol or illicit drugs (Kraemer, 2000). Accidents are the fourth leading cause of death for men in the USA, but the seventh for women (Anderson, 2001). The substantially higher rates of fatal and non-fatal accidents for boys has been partially attributed to a pattern of poor motor and cognitive regulation, leading to a misjudgment of risk (Kraemer, 2000). Epidemiologists are starting to recognize the evolutionary significance of disproportionate male risk-taking in their recommendations for intervention programs (Nell, 2003). Suicide rates for young men in several Western nations are now several times that of young women (McClure, 2000). Social expectations for males to be tough, and discouragement of the expression of emotions such as anxiety and shame may amplify the tendency to take risks (Doyle, 2001; Kraemer, 2000). Some excess male mortality may also result from preferential medical assistance to females in life threatening situations (Moynihan, 1998).

Higher rates of health adverse behaviors such as smoking, drinking, and working in hazardous occupations contribute to excess male mortality (Hazzard, 1986). The recent dramatic declines in male mortality from lung cancer and stroke are due in part to decreases in male smoking rates (Brennan and Bray, 2002). Smoking rates have increased for women (Pampel, 2002), a factor which may narrow the sex difference in

lung cancer and stroke mortality. Males are more likely to die from chronic liver disease and cirrhosis than females, most likely as a result of higher rates of alcohol consumption (Zhang, Sasaki, and Kesteloot, 1995). In industrialized countries, the epidemic of coronary heart disease following several decades after increased consumption of dietary fats has a greater toll on men than women (Lawlor, Ebrahim, and Smith, 2001).

1.4 Historical and cultural influences

Historical changes in human environments have significantly changed mortality patterns. These influences include: the increased spread of infectious diseases through increasing population size, mobility, and the domestication of animals (Diamond, 1997); public health measures such as improved sanitation and vaccination (McKeown, 1979); the development of antibiotics; the emergence of scientific medicine; the increased availability and consumption of fatty foods, alcohol, tobacco, and other drugs (Eaton, et al., 2002); and the widespread availability of automobiles and lethal weapons. These changes have resulted in both the recent dramatic decline in mortality from infectious diseases (Cutler and Meara, 2001) and the increasing prominence of mortality from causes directly or indirectly influenced by behavior, most of which disproportionately affect men. The decline in maternal mortality has also dramatically decreased the female mortality rate and increased the divergence from the male mortality rate; between 1935 and 1956 maternal mortality dropped from 582 to 40 deaths per 100,000 live births in the USA (Guyer, 2000).

Women's health has also been adversely affected by changes from cultural modernization. Increasing caloric intake and consumption of dietary fats has led to earlier menarche (Eaton and Eaton III, 1999), and women in modern societies experience several times more menstrual cycles than women in natural fertility populations (Eaton et al., 1994; Strassman, 1997, 1999). The increase in women's exposure to estrogen and progesterone are likely responsible for increased rates of ovarian and breast cancers (Eaton et al., 1994; Strassman, 1999).

Cultural factors, such as the distribution of mating opportunities and control of resources related to mate acquisition and retention can also impact the M:F MR. The proportion of marriage-aged men to marriage-aged women, or Operational Sex Ratio (OSR; Emlen and Oring, 1977) may be related to the intensity of risky male behavioral strategies and mate competition. Populations with a relatively high OSR have higher male death rates from hostile competitions for the purpose of acquiring resources or mates, especially those with relatively scarce resources (Mesquida and Wiener, 1996). When resources are scarce, the costs of risky male aggression decrease and the potential benefits increase (Wilson and Daly, 1985). The famous Whitehall studies revealed that disease risk is inversely correlated with social status relative to position in a bureaucratic hierarchy, rather than to objective status, even when controlling for numerous health-related behaviors (Marmot, Kogevinas and Elston 1987).

Male-male aggression is highest when only a small proportion of men can acquire sufficient resources to be a desirable mating or marriage partner (Daly and Wilson, 1988). Cultures with polygynous mating systems increase the variance in male reproductive success, raising the intensity of male-male competition and aggression (Betzig, 1986; Chagnon, 1977). Men have lower mortality risks and a longer lifespan when the characteristics valued in mate selection depend less on physical violence and more on prolonged education and training (Peruse, 1993). One hundred million people died from coalition based aggression in Western culture during the 20th century, but if Western conflicts produced the same number of per capita war deaths as in many preindustrial societies, they would have resulted in about two billion deaths (Keeley, 1996).

Specific historical events also impact the ratio of male to female mortality across age groups. The collapse of the Soviet Union led to increased inflation, unemployment, and lower wages (Little, 1998). Physical hardships, social disruption, and social distress associated with the 44% decline in Russia's GDP are believed to have caused 3.4 million pre-mature deaths (Rosefielde, 2001). The increase in mortality rates was more pronounced for men than for women (Little, 1998), although a portion of the increased mortality differential can be attributed to inadequacies in heath care (Andreev, Nolte, Shkolnikov, Varavikova, and McKee, 2003). Male life expectancy declined by six years between 1991 and 1994 (Cockerham, 1997).

1.5 Expected mortality differences in modern populations

These data support the expectation that males tend to have higher mortality rates than females for most causes of death across the life span, with the difference peaking in young adulthood when males reach sexual maturity and begin competing for mates. At this age, we expect to see the highest differences for direct behavioral (external) causes of death, such as homicide, suicide, and accidents. The mortality differences for behaviorally mediated internal causes, such as cardiovascular disease, are expected to peak decades later. Previous evolutionary researchers have made similar predictions (Daly and Wilson, 1985). Although the highest differences are expected for external causes, the greatest proportion of excess male life years lost may now be due to internal causes, because such a high proportion of total mortality now results from internal causes of death that occur late in the lifespan.

The past century in the West has seen a major epidemiological transition from mortality mainly caused by infection, other acute diseases and pregnancy and childbirth, to mortality resulting mainly from chronic diseases related to lifestyle and aging. As the massive and relatively sex indiscriminate death rates from infection decline, and as deaths in childbirth decrease, mortality discrepancies arising from behavioral causes become proportionately much more prominent. Cross-national variation in the sex difference in mortality is expected, as is a generic pattern of peak mortality rate discrepancies in early adulthood and secondary peaks in later adulthood. Finally, we consider whether the overall ratio of male to female mortality

may be a useful population statistic that reflects the severity of male-male competition, environmental uncertainty, and the degree of variance in resources and social status. Documenting the M:F MR across ages and conditions will provide precise picture of the magnitude of mortality differences, allowing for a richer understanding than the acknowledgement of a general sex difference.

2. Methods

In order to examine the difference between male and female mortality rates in various circumstances, we calculated the ratio of male mortality rates divided by female mortality rates (M:F MR) for a number of different populations. We used year 2000 United States mortality data from the National Center for Health Statistics (http://www.cdc.gov/nchs/) to compute the M:F MR by five-year age groups for all causes, external causes, internal causes, and for 11 specific leading causes of mortality: auto accidents, non-auto accidents, cardiovascular disease, cerebro-vascular disease, congenital abnormalities, homicide, hypertension, liver disease and cirrhosis, malignant neoplasms, pneumonia and influenza, and suicide. We then created double Y-axis graphs of the M:F MR for each cause of death, representing absolute male and female mortality rates on a left-sided logarithmic scale and the M:F MR on a right-sided ratio scale. We set the Y-axis intercept for most graphs at 1.0 so that any points above the Y-axis represent mortality rates that are higher for men than women (see Figure 1). We also calculated the excess male life years lost for each cause of death using the formula: ((male death rate x male population size) – (female death rate x male population size)) x mean remaining life expectancy in the age group for a 80 year lifespan.
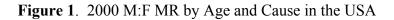
The World Health Organization Mortality Database (http://www.who.int/whosis/) provided data for calculating M:F MR by five year age intervals for twenty countries in the year 2000. Countries were chosen on the basis of the availability of reliable data representing diverse geographic and cultural regions (see Figure 3). We were interested in tracking the M:F MR across the 20th century in the USA, in a culturally similar country with few personal firearms (UK), in a country with substantial cultural gender equality (Sweden), and in a country with a different culture and a non-European population (Japan).
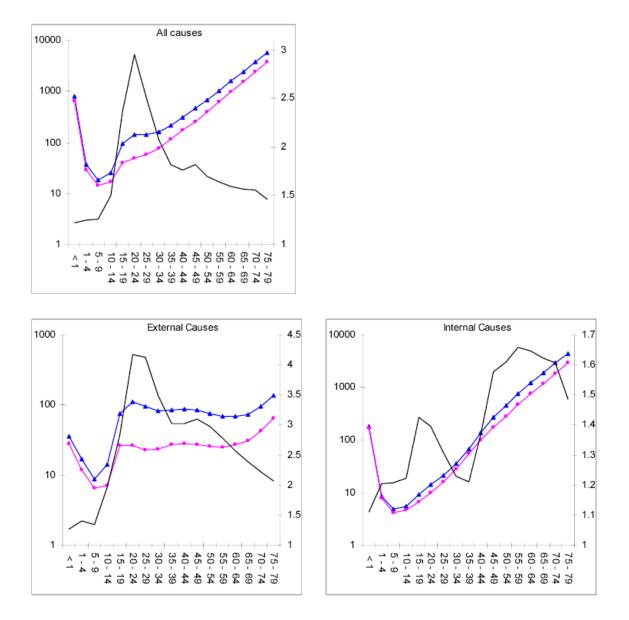
We used the Human Mortality Database, sponsored by the University of California, Berkeley, and the Max Planck Institute for Demographic Research (www.mortality.org), to calculate historical trends in M:F MR from 1930 to 1994 in France, Japan, Sweden, and the USA. A. Whiffen at National Statistics Online (http://www.statistics.gov.uk/) provided UK data (See Figure 4).

3. Results

The year 2000 M:F MR for all causes in the USA showed higher male than female mortality rates across the lifespan. The overall M:F MR exhibited a sharp increase at

adolescence, peaking at 2.94 in the 20-24 year age range, and slowly decreasing to 1.46 for the 75-79 year age range. The M:F MR from external (behavioral) causes was highest in adolescents and young adults with a peak at 4.17 in the 20-24 year age range. The M:F MR for combined internal causes peaked at 1.66 in the 55-59 year age ranges (See Figure 1).
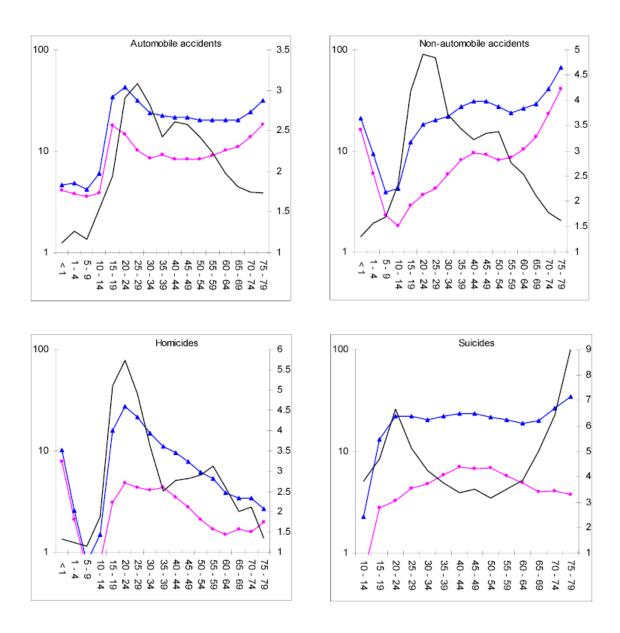
Figure 1. 2000 M:F MR by Age and Cause in the USA

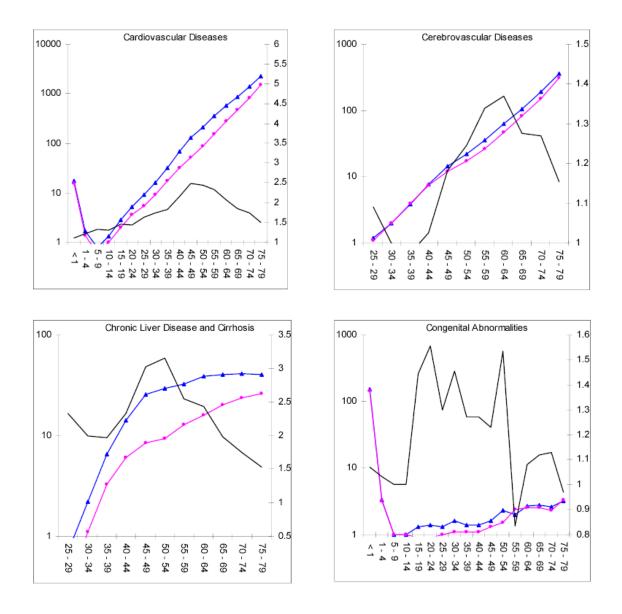**Figure 1**. 2000 M:F MR by Age and Cause in the USA (Continued)

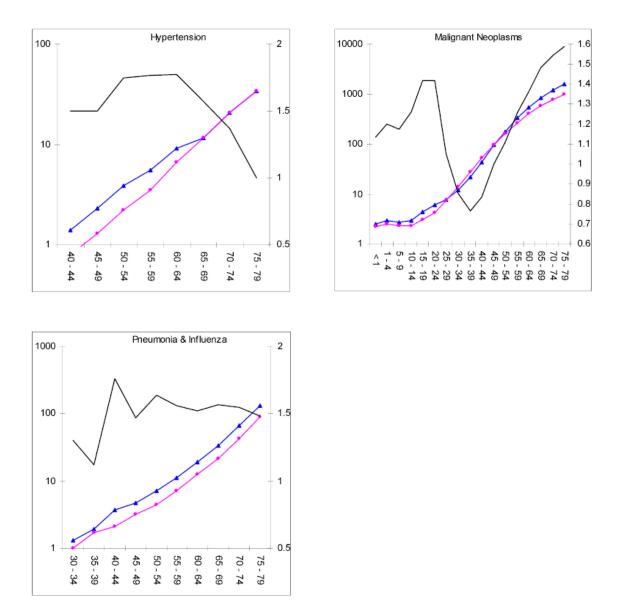**Figure 1**. 2000 M:F MR by Age and Cause in the USA (Continued)

Figure 1. 2000 M:F MR by Age and Cause in the USA (Continued)

Note: The left Y-axis denotes the mortality rate for males and females on a logarithmic scale, the right Y-axis denotes the M:F MR, the X-axis denotes age in years. Blue lines represent male mortality rates, pink lines represent female mortality rates, black lines represent the M:F MR

Males had higher mortality rates in 96.2% of cause by age group combinations. Higher rates of female mortality were in the 30-44 year age range for malignant neoplasms, and in the 10-14 and 35-39 year age ranges for cerebrovascular diseases. The highest M:F MR peak for a specific cause was 9.03 for suicide in the 75-79 year age range. Suicide also had the highest lifespan M:F MR for a specific cause, at 3.90. Homicide and non-automobile accidents followed, reaching peaks of 5.72 and 4.91 respectively in the 20-24 year age range. Chronic liver disease and cirrhosis exhibited the highest M:F MR from an internal cause, peaking at 3.02 in the 45-49 year age range (See Figure 1).

When the data were examined to identify the causes of excess male life years lost, cardiovascular diseases accounted for the greatest proportion (26%), followed by non-automobile accidents (10%), suicide and auto-accidents (both 9%), and malignant neoplasms (8%). Internal causes of death comprised 41% of excess male life years lost, external causes accounted for 35%, causes not included in this study accounted for 23% of excess male life years lost (See Figure 2). The ratio of male to female total life years lost from deaths before age 80 is 1.58:1. The magnitude of the sex difference is perhaps most starkly summarized by the numbers of deaths before age 50; for every 10 premature female deaths, 16 men died prematurely.
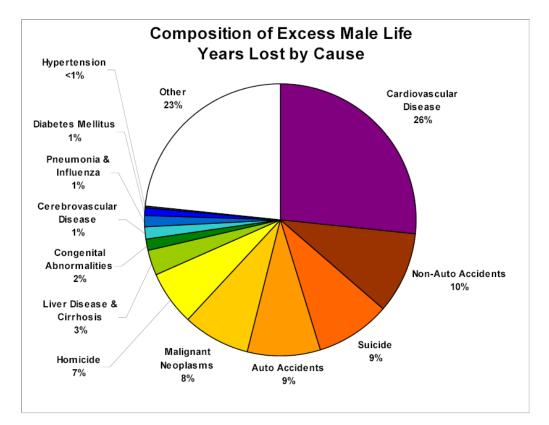
Figure 2. Sources of excess male life years lost by cause in the USA

The cross-national comparison (Figure 3) shows higher male than female mortality for nearly all ages in 20 countries, with a consistent substantial peak at sexual maturity. There is also considerable variation in the magnitude of the M:F MR across nations. While a brief appraisal suggests some contributing factors, much more could be done to characterize the origins of the differences among countries.
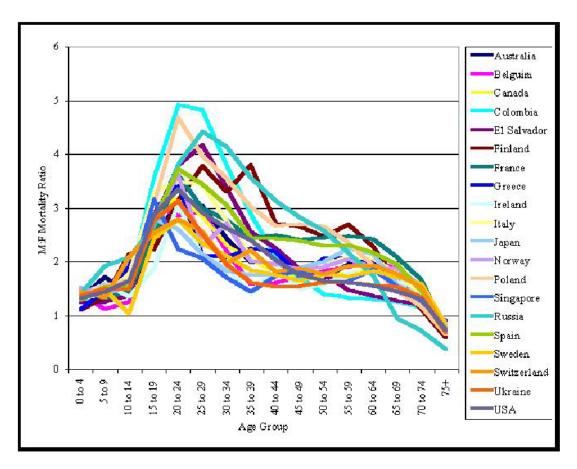
Figure 3. M:F MR in 2000 by Age in 20 Countries

The historical comparison (Figure 4) shows how M:F MR patterns change across time. Two M:F MR peaks are evident, both began to increase markedly around mid-century. The first peak is sharp and centered at the age of sexual maturity. The M:F MR rises quickly beginning about 1940 in the UK, USA, France, and Sweden and a decade later in Japan; the rate of increase slowed in 1970 but continued upwards. The second, more rounded, peak reaches a maximum around age 65. It began rising rapidly about 1930, reached a maximum in 1970 for the UK, USA and Sweden, but has remained high for France and Japan. The general pattern is similar to mortality trends found in Canada (e.g., Andreev, 2000).
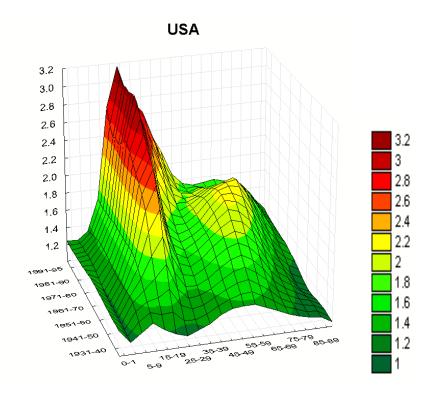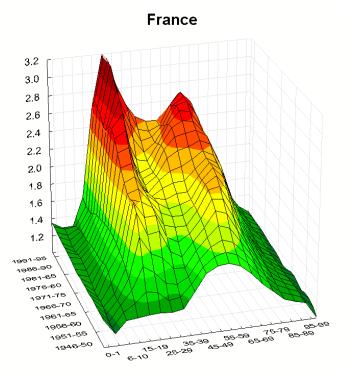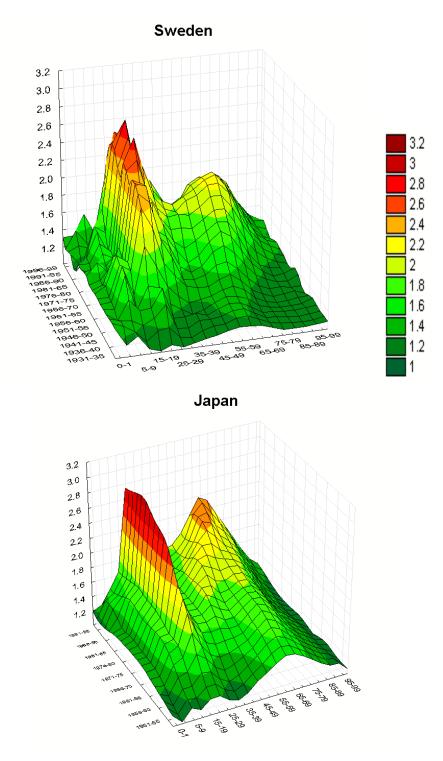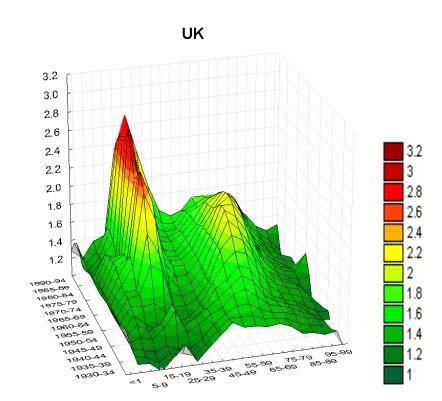
Figure 4. M:F MR by Age in Five Countries over Seven decades

USA

France

Figure 4. M:F MR by Age in Five Countries over Seven decades (Continued)

Sweden

Japan

Figure 4. M:F MR by Age in Five Countries over Seven decades (Continued)

UK

4. Discussion

This paper documents the substantially higher mortality for men compared to women for different causes and across the life-span in different cultures. Being male is now the single largest demographic risk factor for early mortality in developed countries. The results confirmed our expectations that evolved sex differences interact with aspects of current environments to result in considerably higher mortality rates for men than for women, especially in early adulthood and especially for external causes. The mid-life discrepancy in mortality rates from internal causes makes a prominent contribution to the excess number of male life years lost because the preponderance of deaths are at middle age and beyond.

Modern public health and scientific medicine have resulted in an epidemiological transition from mortality mainly caused by infection, other acute diseases and pregnancy and childbirth, to later mortality resulting mainly from chronic diseases related to lifestyle and aging. This transition greatly increases the proportionate contribution of causes of death mediated by behaviors, many of which are risky

behaviors such as smoking, poor diet and reckless driving that cause more deaths in men. External causes of death, resulting directly from behavior, account for the sharp peak in M:F MR at maturity that has emerged and persisted in the past 50 years. In contrast, internal causes of death account for most of the second more rounded peak at age 65 that emerged around 1930, reached a maximum at 2.04 in 1970 and has now decreased below 1.71. The slight decrease in recent decades may result from convergence in male and female smoking rates.

The cross-national variation in the M:F MR illustrates a universal pattern that is influenced by cultural and environmental context. The area under the M:F MR curve, especially from external causes during young adulthood, may prove to be a useful indicator that reflects some systematic characteristics of a culture, perhaps correlating with the severity of male-male competition, political instability, environmental uncertainty, or social inequality. To be useful such an indicator would, of course, need to be corrected for multiple covariates among cultures including overall death rates.

These results suggest three further research questions. The first is to extend our understanding of the proximate causes for excess male mortality by investigating M:F MR variations for specific causes of mortality across additional cultures and historical periods. This would better define the causes for the early adult peak and the late adult peaks that have emerged in the past half-century. The second question is how evolved male characteristics interact with cultural and environmental contexts to influence mortality risk. The tendency to consider "biological" and "social" variables as mutually exclusive alternatives has faded as recognition grows that every phenotypic trait is a product of gene-environment interaction. Nonetheless, it is worthwhile to try to better document the basic differences that arise from sexual selection, and also to determine how they interact with specific aspects of culture to result in patterns such as those observed for the M:F MR.

The comparative method is needed to address this question. Comparisons among diverse human cultures would begin to establish the range and correlates of excess male mortality, with data from hunter-gatherer cultures being especially useful. Some such data is already available. For instance, among the forest dwelling Ache, adult mortality risk for males is 1.47 times that for females. Much of the excess male mortality appears to be related to risky behavioral strategies to gain status and resources; 36% of all adult male deaths were due to coalitional warfare and 8% resulted from status-oriented club fights (Hill and Hurtado, 1996). It would be worthwhile to gather much more such data while it is still available. Comparisons among different species in the wild will also be essential. Although male mammals typically have higher adult mortality rates for males than females (Garilov and Garilova, 1991), the pattern is reversed in many species, usually in conjunction with variations in patterns of parental care (Allman, Rosin, Kumar, and Hasenstaub, 1998). Understanding how sexual selection has shaped traits that make one sex more vulnerable will require correlation of mating patterns and life history characteristics with detailed life tables for many species in the wild.

Finally, research on M:F MR patterns can suggest avenues for intervention. If male mortality rates could be reduced to those for females, this would eliminate over one-third of all male deaths below age 50. As already emphasized, however, these deaths result from complex interactions of sex, behavior and culture, thus forestalling any simple solution. Nonetheless, the general tendency for males to take greater risks ties together many preventable causes of death, and is a worthy focus for interventions.

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Note

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