PRELIMINARY EVIDENCE REGARDING THE HYPOTHESIS THAT THE SEX RATIO AT SEXUAL MATURITY MAY AFFECT LONGEVITY IN MEN*

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In human populations, variation in mate availability has been linked to various biological and social outcomes, but the possible effect of mate availability on health or survival has not been studied. Unbalanced sex ratios are a concern in many parts of the world, and their implications for the health and survival of the constituent individuals warrant careful investigation. We indexed mate availability with contextual sex ratios and investigated the hypothesis that the sex ratio at sexual maturity might be associated with long-term survival for men. Using two unique data sets of 7,683,462 and 4,183 men who were followed for more than 50 years, we found that men who reached their sexual maturity in an environment with higher sex ratios (i.e., higher proportions of reproductively ready men) appeared to suffer higher long-term mortality risks than those in an environment with lower sex ratios. Mate availability at sexual maturity may be linked via several biological and social mechanisms to long-term survival in men.

In human populations, variation in mate availability, as indexed by sex ratios, has been linked to various social outcomes, such as marriage market performance, family formation, labor supply, and prevailing gender roles (Angrist 2002; Fossett and Kiecolt 1993; Guttentag and Secord 1983; South and Trent 1988; Trent and South 1989). It is conceivable that mate availability may affect long-term health and survival via some of these demonstrated effects on social processes, as well as via other, biological pathways. To our knowledge, however, no effort has been made either to theorize or to empirically examine any such health effects of mate availability in humans. Nevertheless, unbalanced sex ratios are a concern in many parts of the world (Attane 2006; Das Gupta 2006; Sen 1992), and their implications for health and survival warrant careful investigation. Here, by using two unique data sets of 7,683,462 and 4,183 men who were followed for more than 50 years, we examine the provisional hypothesis that sex ratios faced by human males at their sexual maturity may affect their long-term survival.

Based on evidence from demographic and sociological research on the social effects of mate availability, we identify several pathways through which mate availability may affect human survival. While it is unclear to what extent various social and biological processes might mediate the relationship between mate availability and human health and survival, three pathways suggest a survival disadvantage for the supernumerary sex. In outlining these pathways, we acknowledge that we are not yet in a position to adjudicate among them, but we nevertheless wish to identify biological and demographic theories that support the plausibility of the hypothesized link between mate availability and mortality in humans.

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First, skewed sex ratios have been linked to delays in marriage and an increase in the absence of marriage in the supernumerary sex (Guillot 2000; Kiecolt and Fossett 1995; Trovato 1988; Watkins 1984). A substantial literature has shown that spouses contribute to each other's health and survival; the salubrious effects of marriage are quite substantial and are accumulated over the life course (Elwert and Christakis 2006; Rogers, Hummer, and Nam 2000; Waite 1995). Delays in marriage and absence of marriage may therefore lead to a reduction in the cumulative marital benefits on health accrued over the life course for the supernumerary sex.

Second, in the marriage market, the rarer sex enjoys more bargaining power and therefore may be able to attract a higher-quality spouse in terms of the spouse's health, financial and social resources, and willingness to invest in the marriage (Pollet and Nettle 2008). Spousal quality mediates the health benefits that men and women derive from their marriages (Bartley et al. 2004; Jaffe et al. 2006; Monden et al. 2003). In the situation of unbalanced sex ratios, the average member of the supernumerary sex would settle for a lower-quality spouse, conditional on entry into marriage. Consequently, the salubrious effects of marriage for the supernumerary sex may be diminished.

Indeed, in the household division of labor, wives are traditionally charged with taking care of the health needs of household members (Harrison 1978; Stolzenberg 2001; Umberson 1992). Therefore, men's health especially benefits from the contributions of their wives (Jaffe et al. 2006; Kiecolt-Glaser and Newton 2001; Lillard and Waite 1995). Consequently, delays in marriage, absence of marriage, and limited partner choices due to skewed sex ratios might be more relevant to men's health than to women's.

Third, skewed sex ratios may result in intensified competition for sexual partners and induce stress for the supernumerary sex. It has been increasingly recognized that early-life conditions can have very long-term biological effects in humans (Hayward and Gorman 2004) and that stressors may have cumulative effects on survival (Seeman et al. 2001). Studies have started to uncover the biological processes through which early-life stressors may affect health and survival in later life. Competition for potential partners may be such an early-life stressor.

A limited number of animal studies have examined the effects of sex ratios on animals' health and survival. Although findings from animal studies might not be directly applicable to human populations, in the absence of similar studies in humans, they might offer some guidance to our understanding of the possible relationship between sex ratios and survival and of the mechanisms that mediate this relationship in human populations. Animal studies have found that sex ratios affect animals' health and survival through their effect on courting behavior, reproductive activity, and mate choice (Burley 1985; Fleming 1996; Millesi et al. 1998). Some of the mechanisms of sex ratios studied in animals, such as the stress of mating competition and mate choice, are analogous to the pathways we have posited in humans. These findings lend further credence to the hypothesis that sex ratios should affect human survival.

Given the plausible biological and social mechanisms, we expect that sex ratios during sexual maturity might have a significant effect on long-term human survival and that the supernumerary sex should be disadvantaged. Moreover, the effects of sex ratios might be more pronounced for men than for women. We use two unusual data sets to explore the link between sex ratios during sexual maturity and survival in human males. In the following sections, we first describe the construction of the two data sets, the methods employed to analyze the data, and the results. Discussion and conclusions follow.

DATA AND RESULTS

We use contextual sex ratios to index mate availability. The two data sets we used allowed us to ascertain both the sex ratio at the *population* level and actual survival at the *individual* level. Population-level sex ratios in human societies have been shown

to be valid measures of the availability of potential partners (Fossett and Kiecolt 1991; Lampard 1993).

We first examined the relationship between the sex ratio and survival using a longitudinal data set of a cohort of high school graduates from a single state. The Wisconsin Longitudinal Study (WLS) is based on a one-third sample of all 1957 high school graduates in Wisconsin. Cohort members have been surveyed four times between 1957 and 2004 (Hauser and Roan 2006; Hauser and Sewell n.d.). We computed the sex ratios of respondents' entire graduating class at their own high school (not just that of the one-third sample) based on WLS records. The sex ratio is defined as the percentage in the entire graduating class who are men. Mortality information was obtained from survey tracing operations, mortality closeout interviews with proxy respondents, and the Social Security Death Index (N = 1,194 dead, out of 10,317, as of 2004). This data set permitted examination of the relationship between the contextual sex ratio in a person's late teens and his or her mortality over the life course up to roughly age 65.

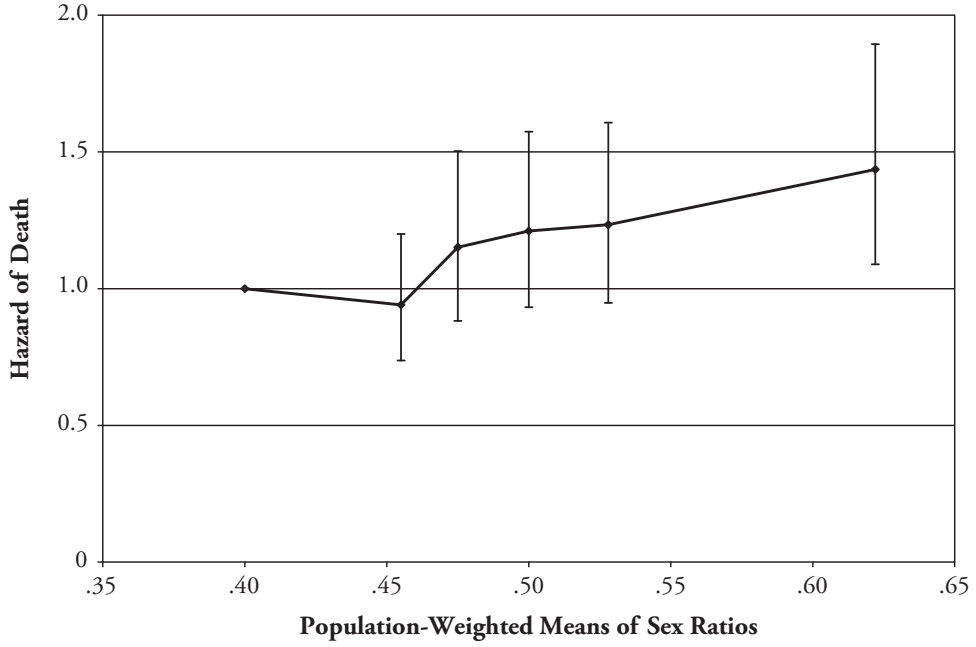
We estimated a Cox proportional hazards model with shared frailty for schools. The shared frailty allows for the possibility that other school-level variables besides the sex ratio influence the hazard of death. Given the much smaller sample here than in the Medicare sample described below, and the consequent reduction in statistical power, we first estimated a model with a linear term for the sex ratio. The model controlled for individual-level measures of high school academic performance, such as class rank and test scores, parental socioeconomic status, and whether the respondent grew up on a farm. Although it is desirable to account for individual health status measured in high school, such information is not available. We did not include any measures of post–high school circumstances because these would be potential mediators of the effect of interest (i.e., possibly on the causal path). Respondents who attended same-sex schools are excluded from the analysis (for both conceptual and computational reasons), leaving 4,183 male and 5,063 female respondents from 411 schools.

These WLS analyses suggested that the sex ratio was positively associated with the hazard of dying for men (p = .02, two-sided tests) but not for women (p = .66, two-sided tests). More specifically, net of controls, a percentage-point increase in the males in one's graduating class increased the hazard of dying before age 65 by about 1% for men. For comparability with the state-level analyses described below, we divided the respondents into sextiles based on school-level sex ratio and graphed the hazard ratios against the population-weighted mean in each sextile in Figure 1.

The preceding analysis suggests that the variation in the sex ratio at sexual maturity in a local environment predicts mortality over the life course of men. Next, we compiled a data set of 12.7 million elderly American men who were enrolled in Medicare as of January 1, 1993 (Christakis and Allison 2006), and explored the relationship between the sex ratio and mortality on a national level and into old age. This data set captures 96% of all men who were 65 years of age or older in the United States, with a mean age of 71. These men were followed up until January 1, 2002, and their survival status and death dates were ascertained. We also collected detailed information on birth dates, race, and current state of residence. Given well-known differences in marriage behaviors between whites and blacks, we used only whites (89% of the sample) in our analyses (Elwert and Christakis 2006). From the Social Security numbers (SSNs) of the men, we determined the year and state in which they obtained their SSNs (Block, Matanoski, and Seltser 1983; Lauderdale et al. 1997). About 72% of the men obtained their SSNs between ages 15 and 25, when courting and marriage typically took place from the 1930s to 1950s. Our primary sample consisted of 7,683,462 such elderly men.

We used decennial U.S. census data to calculate state-level population sizes for marriage-age males and females for 1930, 1940, and 1950; we then interpolated intercensal population sizes using the exponential function. We focus on unmarried persons of

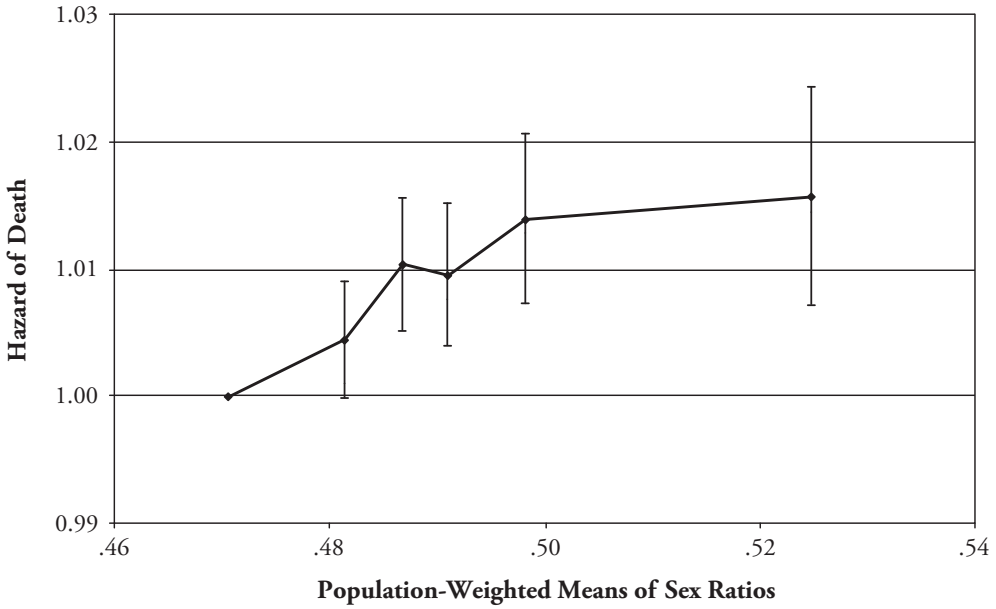
Figure 1. Mortality After High School for Men and School-Level Sex Ratios in the 1957 Graduating High School Class for the State of Wisconsin (*N* = 4,183)



Notes: Sex ratios were computed as the number of males divided by the total number of students in the graduating class of a high school. The *x*-axis represents the population-weighted means of sex ratios in sextiles of sex ratios. The hazard ratios were estimated in Cox proportional hazard models with shared frailty for schools that controlled for individual-level measures of high school academic performance and parental socioeconomic status. Also shown are 95% confidence intervals.

marriage age in defining the sex ratios because our hypothesis suggests that the sex ratio in an individual's environment at the time of sexual maturity affects his or her health in the long run. We are therefore specifically interested in mate availability for individuals in their late teens and early to mid-20s. Because individuals typically compete with others of similar age for potential mates, we used an age range of 10 years (15–24 for women and 18–27 for men) when we constructed measurements of the sex ratio. During 1930–1950, the median age at first marriage for men and women differed by 2.5 to 3 years. We therefore enforced a three-year age difference in the ranges of marriage age for men and women in the computation of the population ratios. The sex ratio was defined as the number of unmarried men ages 18 to 27, divided by the sum of such men and the number of unmarried women ages 15 to 24. Such a definition of the sex ratio has often been used to measure mate availability (Goodkind 1997; Guttentag and Secord 1983). The sex ratio was calculated for each year in each state. For men who obtained their SSNs between ages 15 and 25 in a given state, we assumed that they courted and married (or at least spent some time courting) in that state. We assigned to each individual the state-specific sex ratios in the year during which they turned 20 (1933–1948 in our sample).We examined the effects of the sex ratios on survival in old age for the men using Cox proportional hazard models with state-level fixed effects. These fixed effects result in a different baseline hazard function for each state, such that the analysis accounts for any stable measured and unmeasured attributes of the states that might affect survival of the men residing there. To allow for flexible specification of the functional form of the sex ratio, we divided the sex ratio into sextiles and used five dummy

Figure 2. Mortality in Old Age (65+) for Men and State-Level Sex Ratios in Men's Youth in the United States (*N* = 7,683,462)



Notes: Sex ratios were computed as follows: unmarried males (ages 18–27) / [unmarried males (ages 18–27) + unmarried females (ages 15–24)]. The *x*-axis represents the population-weighted means of sex ratios in the sextiles of sex ratios. The hazard ratios were estimated in Cox proportional hazard models with state-level fixed effects that controlled for men's age as of 1993, and state-level unemployment rates and percentage of families living on a farm in men's youth. Also shown are 95% confidence intervals.

variables to represent the sextiles in the model. The Medicare sample is limited by the lack of data on characteristics of the men in their youth. But we controlled for time-varying state attributes that may correlate with the state-level sex ratio and affect health in late life, such as state-level unemployment rates and the percentage of families living on a farm in the year when the men were age 20. We also controlled for the men's age as of 1993.

During the nine-year follow-up period beginning in 1993, 41% of men died. As in the WLS sample, estimation of the foregoing model indicates that a higher sex ratio at the time of men's sexual maturity was associated with a higher risk of mortality during late life. Figure 2 graphs the hazard ratios of death against the population-weighted mean of the sex ratio in each sextile. Compared with men who reached sexual maturity in an environment (state and year) with the lowest sex ratios (range = 0.44–0.48; mean = 0.47), the hazard of death for those in an environment with the highest sex ratios (range = 0.50–0.66; mean = 0.52) was about 1.6% higher. Given that in 1993 a 65-year-old white man, on average, could expect to live another 15.4 years (National Center for Health Statistics 2003), the increase in the hazard of death associated with higher sex ratios measured at the statewide level can be translated to a reduction of three months of life expectancy at age 65 (which is comparable in size to the benefits seen with various health behavior changes recommended for the elderly).

We explored the sensitivity of our findings in the Medicare sample by using different specifications of the sex ratio. We also assessed the potential biases introduced by military recruitment of men during World War II by excluding men who turned 20 during

1942–1946. The negative relationship between the sex ratio and late-life mortality was unchanged.

The hazard ratio estimates of the effects of the sex ratio on survival are much larger in the Wisconsin sample than in the Medicare sample. This difference is expected given that school-level sex ratios provide a much more fine-grained measure of mate availability in an individual's immediate environment than does the state-level sex ratio. In addition, the age over which the effect is estimated in the Wisconsin sample is much younger than in the Medicare sample, and closer to the men's "exposure" to the sex ratio. Nevertheless, in both of these analyses, which use two samples that differ in a variety of ways, the basic relationship between the sex ratio at sexual maturity and male survival is qualitatively the same.

CONCLUSIONS

We used the sex ratio at sexual maturity as an indicator of mate availability and assessed a novel hypothesis regarding the possible relationship between this early-life condition and long-term mortality in humans. Specifically, we suggested that an imbalanced sex ratio may affect positions in the marriage market, marriage formation, and stress in the mate-finding process that might in turn result in unfavorable long-term health outcomes and reduce longevity. In a first empirical exploration of this hypothesis, we analyzed a representative sample of all 1957 Wisconsin high school graduates and a unique, large Medicare-based sample of elderly men with long-term mortality follow-up. Results indicate that men who experienced higher sex ratios at sexual maturity indeed appeared to suffer higher mortality in old age. This analysis accounts for observed early-life conditions on the individual and state level, as well as certain dimensions of unobserved heterogeneity through fixed- and random-effects models. Nevertheless, we recognize that confounding social and economic factors may remain to jointly account for variations in early-life sex-ratio imbalances and late-life survival.

These findings are consistent with a link between mate availability at the time of sexual maturity and long-term health and survival, mediated by the mechanisms of delays in marriage, absence of marriage, limited partner choices, and stress induced by competition for partners. Our data do not allow us to distinguish among these competing mechanisms, but descriptively establishing a link between mate availability and long-term survival in humans constitutes an important first step in understanding the health effects of this early-life condition.

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