Are we approaching a biological limit to the length of human life?

Dr David McCarthy[1]*, Dr Po-Lin Wang[2]
[1]University of Georgia, [2]University of South Florida

Abstract

Researchers have discovered persuasive evidence that mortality at older ages is being postponed, yet human longevity records have increased only slowly. We reconcile these two findings by fitting the Gompertz mortality law to birth cohorts using a Bayesian technique to surmount cohort censoring. We show that people born before around 1900 – so those currently reaching the ages at which longevity records can be broken – did not actually enjoy significant mortality postponement at older ages. But evidence for old-age mortality postponement is very strong for people born after 1900, who will reach those ages soon. We project that the longest-lived person born in 1950 will survive around 15 years longer than the longest-lived person born in 1900 in most of the countries we study. Japanese females are at the forefront of this transition. Our results support the view that if there is a maximum biological limit to the human lifespan, we are not yet approaching it.

Introduction

Some researchers have interpreted recent significant improvements in old-age longevity in rich, industrialized countries as evidence of the outright postponement of ageing, and therefore asserted that if there is a maximum biological lifespan, we are still far from it.[1,2] Others have pointed out that despite mortality improvements at younger old ages (ages 50-80) and consequent increases in remaining period life expectancy, human longevity records have not increased much over the last 30 years, suggesting the opposite.[3,4] Reconciling these two findings is crucial, because if we have not reached a biological limit to human life, increases in human longevity could be open-ended. Most previous research on human longevity has used period-based approaches.[17-22] In contrast, here we analyse longevity after age 50 by birth cohort in 19 rich, industrialized countries, using a Bayesian technique[23-25] to surmount cohort censoring caused by survival. We show that while mortality compression (where mortality at younger old ages improves but there is a fixed upper limit on age[6]) is the dominant historical pattern, we find evidence for episodes of mortality postponement, suggesting that observed maximum human lifespans did not, and still do not, represent a biologically-determined maximum. The cohorts who would be old enough to have broken longevity records primarily experienced mortality compression, but cohorts who reached age 50 after around 1950 are experiencing the most significant episode of mortality postponement recorded in our data in every country. As these cohorts attain advanced ages over coming decades, we anticipate that old-age longevity records in these countries will increase by between 10 and 15 years. Our work implies that current demographic projections likely understate the extent of future population ageing and we anticipate that the Bayesian technique we have developed will permit a greater and long-overdue focus on cohort-based analyses in human longevity and other areas.

Methods and Materials

We define the base mortality of individuals aged x and born in year c as $\mu_{x,c}$ and use the Gompertz law to write:

$$\log(\mu_{x,c}) = \lambda_{50,c} + \delta_c (x-50),\ 50 \le x \le 100 \qquad (1)$$

where δ_c is the DRCA of cohort c and $\lambda_{50,c} \equiv \log(\mu_{50,c})$. This approach makes the assumption that each cohort is endowed with δ_c and $\lambda_{50,c}$ at age 50, and that these remain fixed thereafter. We therefore write the observed central rate of death at age x of an individual born in year c, defined as $m_{x,c}$, as:

$$\log(m_{x,c}) = \log(\mu_{x,c}) + \varepsilon_{x,c} \qquad (2)$$

We estimated equation (2) using population mortality data, organized by birth year, for males and females between the ages of 50 and 100 for a set of 19 rich industrialized countries from the Human Mortality Database. Our Bayesian approach[23-25] provides a joint posterior distribution of the parameters $\lambda_{50,c}$ and δ_c over all cohorts in our data, denoted $\{\tilde{\lambda}_{50}, \tilde{\delta}\}$. We denote the mode of this distribution as $\hat{\lambda}_{50}$ and $\hat{\delta}$.

We used our estimates of $\{\tilde{\lambda}_{50}, \tilde{\delta}\}$ from equation (2) to quantify the changes in remaining cohort base life expectancy at age 50 between cohorts born ten years apart due to compression and postponement. See FIGURE 1.

Results

Because Sweden has the longest data series in our sample, and exhibits patterns that are widely similar to other countries, we focus on results from Sweden before turning to other countries. FIGURE 2 shows log observed mortality hazard rates by age for Swedish males for cohorts born ten years apart from 1880 to 1950 (dots), along with our estimates of log base mortality (lines, calculated using $\hat{\lambda}_{50}$ and $\hat{\delta}$. We find that cohorts born after 1910 will continue to enjoy mortality postponement unless there is a dramatic increase in their DRCA's only at older ages, a pattern for which there appears to be little or no historical precedent.

The pattern of postponement and compression described previously, and strikingly evident in FIGURE 2, is clear. We project that Swedish females born in 1950 can expect to live 7.5 years (males: 9.5 years) longer after the age of 50 than their counterparts born 50 years earlier. 60% (males: 70%) of this increase will be due to postponement. Postponement, but not compression, is projected to end for cohorts born after 1950 (although again these estimates are highly imprecise). See Panel B of FIGURE 3.

For cohorts born before 1900, the mean of M_c, the maximum observed lifespan, increases due to increases in population, mortality compression and small amounts of postponement. But for cohorts born after 1900, the dramatic period of mortality postponement identified in Panel B is projected to raise the observed maximum lifespan significantly in addition to the increases caused by population change. See Panel C of FIGURE 3.

FIGURE 1: Dividing changes in mortality rates between compression and postponement

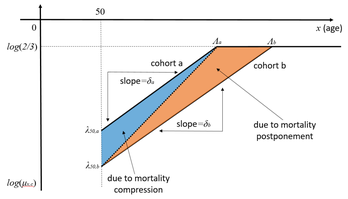


FIGURE 2: Observed mortality hazard rates (dots) and estimated base mortality hazard rates (lines) by age for Swedish males born 1880-1950

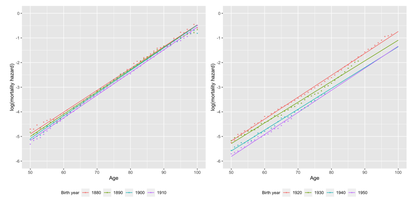
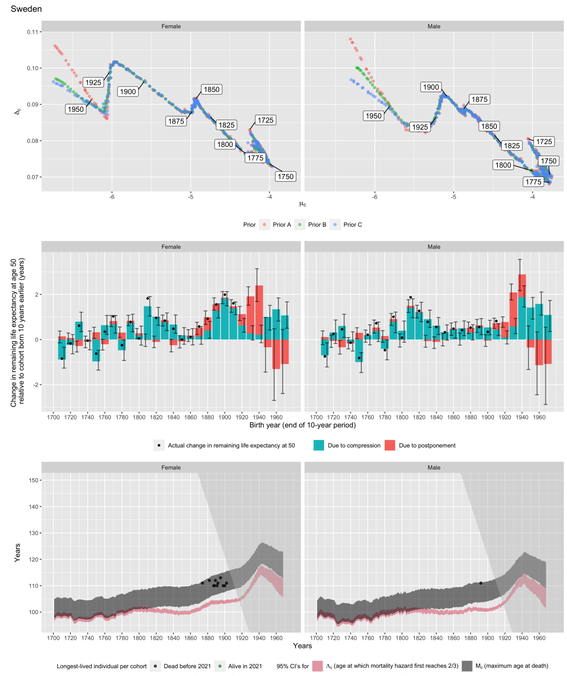


FIGURE 3: Bayesian estimates of slope and intercept parameters of male and female cohorts for Sweden (panel A); implied changes in remaining cohort base life expectancy at age 50 over ten-year birth cohorts, divided into the portion due to postponement and portion due to compression (panel B), and 95% confidence intervals for the age at which cohort mortality hazard first reaches 2/3 (Λ_c) and the maximum observed lifespan (M_c) in each birth cohort (panel C).



NOTE: Confidence intervals are not shown in Panel A for ease of interpretation. In the other panels, bands or bars show 95% confidence intervals for the true base value. In panel B, bar heights show median estimates. Black dots show the actual change in life expectancy for extinct cohorts. Note that under the assumption that the model is correct, this would equal the true base value plus random error due to calendar-year effects and random variation, plus the change in bias due to these. In panel C, black dots show the longest-lived person in each birth cohort from ILD[26] and GRG[27] data (green if they are still alive in 2021). The mean of increases in line with the logarithm of cohort size at age 50 even if there are no changes in mortality rates. The shaded area to the right of the diagonal line in panel C indicates censoring in 2021.

Conclusions

We have shown that while mortality compression has been the dominant pattern over most cohorts in our data, there have been intermittent episodes of mortality postponement. By far the most significant of these is currently occurring, in cohorts that reached age 50 in the second half of the twentieth century, a period associated with significant technological advances in healthcare and elsewhere, and large increases in living standards. There is therefore significant potential for longevity records to be broken over the next few decades, a finding strongly consistent with previous work asserting that humans are not yet approaching a biological maximum life, if one even exists[1,2]. We emphasise, however, that our projections are by no means guaranteed. Rather, their realization will depend on continued political, environmental and economic stability, and policy choices that continue to support the health and welfare of the elderly. The emergence of Covid-19 and its outsize effect on the mortality of the elderly provides a salutary warning that none of these is certain. But if our projections do come to pass, the implications for human societies, national economies and individual lives will be profound.

***CORRESPONDING AUTHOR**

David McCarthy
University of Georgia
Email: dmccarth@uga.edu

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UNIVERSITY OF GEORGIA 1785

UNIVERSITY of SOUTH FLORIDA