Title: Median/modal death ages of European males were near-constant for ~30 years.

Running head: Male death-age averages constant: ~30y

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ABSTRACT.

Background. Longevity is of considerable interest. Collation of recent data after World War II by the Human Mortality Database allowed Analyses, previously unattainable, of modal death-ages for sufficient numbers of large European cohorts. **Objective.** to track all-cause "bulk" mortality for both sexes. **Methods.** The only high-quality, large-number Lexis data available were pooled from nine European countries and raw-data modes (and means/medians ≥60 years old (y)), plus thin-plate-spline averages, were analyzed. **Results.** Here we show that over a period of ~30 years (cohorts 1880-~1910) dramatic sex differences existed between raw-death-age changes: male modal ages being near-constant (77.2y ± standard deviation 1.58y); female modal ages increased. For available cohorts (1880-1904) male raw medians were exactly constant (76y); male means showed slight increase (0.0193y/year; compare female: 0.146y/year). Male deaths ≥60≤76y compared with >76y, as percentages of total, were near-equal, whereas in females the former decreased. Only after ~1910 did male modal ages rapidly increase (other averages not calculable). **Conclusions.** It might have been expected that death ages would increase for everyone over this period, but results indicated otherwise. It is commonly assumed that improved environment generally translates into increased longevity for everyone, but females might have responded more than the bulk of adult males during this period.

Keywords: Cardiovascular Disease; Demography; Longevity; Thin-plate Spline.

INTRODUCTION

Longevity is of considerable interest, not least because some parameters have shown recent increases in numbers of people over 65 to 80 years old (y), for example in Europe, India and China[1]. The latest European Union's "Ageing Report" (2018; https://ec.europa.eu/info/publications/economy-finance) states: "In the EU, life expectancy at birth for males is expected to increase... from 78.3 in 2016 to 86.1 in 2070 [and] for females... increase.... from 83.7 in 2013 to 90.3 in 2070”; and also noted that care costs for older people should rise. In the popular press Forbes Magazine (02-04-2018, Haseltine: https://www.forbes.com/sites/williamhaseltine) stated: "Elder... care is rapidly becoming one of the most daunting healthcare challenges of our day. Between 2015 and 2030, the number of people ... aged 60 years or over [should] grow by 56%". Recently Christensen et al.[2] stated ”...we do not have to look to the future for challenges of an ageing population: the oldest-old group (aged >85 years) have ... been the most rapidly expanding segment of the population in developed countries.”

However, there are some concerns over whether this translates into a lay person's view of increased longevity, which often means an expectation that adults will generally live to increased ages barring mishap: accidents and/or infectious disease; often presuming the existence of "healthy" ageing, included in "life-style" mortality e.g. with cardiovascular diseases and cancer (with risk factor (s) partly affected by life-style)[3].

In the BBC news item "Do we really live longer than our ancestors ?"; (2018, Ruggen; http://www.bbc.com/future/story/20181002-how-long-did-ancient-people-live-life-span-versus-longevity) ancient Greek/Roman elite males (n=158) were stated to have lived a median age 72 y, comparable to modern famous-males: 70 y i.e. similar to that two thousand years ago [4] ! (It could be argued the small samples were biased.)

Additionally, although middle-ages average male lifespan was 31.3 y; this has been interpreted to mean that many died young but privileged people past teenage might have lived much longer (Popes lived a median of 66 y in 1200–1599 and 77 y in 1600–1900);[5]. From 1200-1745, elite median longevity was estimated to be ~62-70 y for those who lived past 21 y who didn't die from accident, violence or poison (the 1300s bubonic plague was consequential).[6] One study[7] analyzed noblemen (n=115 650) and estimated a median longevity increase from 800 to 1800 CE: from ~45 to 60 y, mostly by reduction in violent deaths. Most interestingly womens' 1800 median longevity was 70 y.

The above does not seem to give a clear picture concerning possible life-style mortality. Additionally, life expectancy is useful for future prediction or when cohort data is not available. It is a period mean of means of age classes from different cohorts taken at one time, and changes will be greatly (perhaps entirely) affected by deaths of the very young or the oldest old (and changes might not apply to the "bulk" of adult deaths). A life expectancy parameter value for one cohort is amalgamated from many previous cohorts and, as such, will only correspond roughly to the cohort parameters for that cohort. Doubts can be expressed whether (1) life expectancy has mostly changed due to decreases in earlier deaths or due to (2) a small proportion of the oldest older people living longer (perhaps genetically endowed), without changes to adult "bulk" deaths. Additionally, some values given above might reflect that (3) there are now more people and therefore more older people, with the adult distribution shape staying constant and (4) some studies do not differentiate sexes and possible differences.

One question is therefore: should a lay person be optimistic that the bulk of the late-adult population is actually living on average longer (the bulk being here loosely defined as the hump in the mortality curve from around 60 y to 90 or 100 y) ?

Cardiovascular diseases have given the leading cause of world mortality. Since the 1980s, national health surveys have collated physiological damage markers as precursors of morbidity based on cardiovascular risk assessments, but also stressors/diseases[3] and inflammation markers. In one theory, delayed ageing results from the simultaneous lowering of fatal/disabling disease risks. "Healthy ageing" theoretical frameworks have been developed, and contemporary "life-style" mortality can be attributed e.g. with risk factors from obesity and/or smoking.[8] As deaths due to war, famine and infectious diseases decrease it is possible that the "bulk" of adult deaths will increasingly be determined by lifestyle, including "healthy" (if such a thing exists), mortality. The death distributions of all-cause mortality are therefore likely to become of great interest, especially in high-income countries, as these might start to reflect underlying biological mechanisms of aging.

It is therefore of interest to use cohort central-tendency parameters which describe "bulk" death-ages without being greatly affected by younger deaths, for example the mode (or median above a certain age). This is now possible due to sufficient cohorts with full data recently available. The question investigated was whether the oft-stated increase in longevity is reflected in increases in measures of central tendency including death-age density modes or medians.

It was determined to monitor death-density-curve modes with highly-accurate cohort data from the Human Mortality Database (HMD; www.mortality.org), pooled from all countries with Life-Table Lexis data (curated to the highest quality): Denmark, Finland, France, Iceland, Italy, Netherlands, Norway, Sweden and Switzerland. The subject of this paper therefore concerned all-cause old-age mortality (including life-style mortality and/or healthy aging) with cohorts from 1880 to 1919, chosen to include sufficient data both sides of the mode to allow spline fits or to avoid World-War-II direct death increases. Raw data, or thin-plate spline interpolation, were used.

Additionally, medians and means were calculated for cohort "bulk" deaths, arbitrarily defined as ≥60 y, using raw data or spline integration.

An important aspect of the work was that there were apparently no other high-quality Lexis data available anywhere with sufficient numbers of individuals to give reasonably smooth death-density curves.

The main a priori hypothesis was that there are changes in the modal death-ages over time in either sex and the main aim of the work was to study changes in death-age averages for as many cohorts as possible, for both sexes, from high-quality European data.

RESULTS.

From large sample-size cohorts, created by pooling life-table cohort data from nine European countries (separately for males and females), raw data or thin-plate spline fits allowed changes in mortality density averages to be followed. Typical mortality density curves (using relative numbers of deaths estimated from dx data; dx') for males and females (cohorts 1881 C.E.) are shown in Fig 1. Fig 1b shows the bump at ~65 y from direct male World-War-II deaths, which deterred use of cohorts before 1880 C.E..

FIGURE 1

Fig 2 shows cohort modes from (a) raw data (b) thin-plate splines, against cohort (given as age at which the cohort has 110 years). Over the first ~30 years, dramatic differences between modal changes for males and females over time were evident (more clearly seen with interpolation; Fig 2b): average modal ages for male bulks were near-constant whereas females showed a large and significantly different increase (see Table 1). Fig 3 and Table 2 show how raw cohort means and medians (≥60 y) changed over time: male medians constant at 76 y, whereas means increased slightly; female averages increased dramatically over this period. (Integrated median/mean graphs were similar and can be generated from coding files.)

FIGURE 2

FIGURE 3

Kendall independence tests showed significant differences between sexes for all averages (Table: 1,2; effect sizes given). Further statistics including effect sizes for linear regression and confidence intervals (for Kendall independence tests) are given in Supplemental-file-S5. Fig 4 compares numbers of deaths (as percentages of total deaths) from ages ≥60 to 76 y, with deaths above 76 y. For males these were near-equal for the 25 years available, whereas with females the former decreased steadily.

FIGURE 4

Table 1. Male, female MODAL and gradient death-age parameters from raw data or thin-plate splines.

Population fraction, Cohorts	**Method[1]**	**MODES**		**Gradient[2] (y/y), Kendall p**	**Male vs. female independence test p value, effect size**
		global mean ± S.D. (y)	**range (y)**		
MALES, 1880 to 1919 (n=40)	Interpolated	78.3 ± 1.51	76.0 to 81.6	0.0801, p=0.0140	p<0.001, r=1.17
	Raw data	78.2 ± 2.28	73.5 to 82.5	0.108, p<0.001	p<0.001, r=0.465
FEMALES, 1880 to 1919 (n=40)	Interpolated	84.3 ± 2.62	80.5 to 89.0	0.221, p<0.001	-
	Raw data	84.3 ± 2.83	78.5 to 89.5	0.219, p<0.001	-
MALES, 1880 to 1909 (n=30)	Interpolated	77.6 ± 0.578	76.0 to 78.5	-0.0251, p=0.0353	p<0.001, r=1.41
	Raw data	77.2 ± 1.58	73.5 to 80.5	-0.0214, p=0.558	p<0.001, p=0.684
FEMALES, 1880 to 1909 (n=30)	Interpolated	83.1 ± 1.90	80.5 to 87.1	0.208, p<0.001	-
	Raw data	83.1 ± 2.19	78.5 to 87.5	0.203, p<0.001	-

Note. [1]Thin-plate spline interpolation or raw data. [2]Line of best fit (no assumptions made concerning linear model if *t* p not applicable). Kendall p = Kendall rank correlation p value; -: value given in male row; S.D. = standard deviation; Column "global Mean" = mean over all cohorts. All values given to three significant figures (or range: one decimal place).

Table 2. Male, female (≥ 60 y) median or mean death-age parameters from raw data or thin-plate splines.

Population fraction, Cohorts	Method[1]	Global mean ± S.D. (y)	range (y)	Gradient[2] (y/y), Kendall p	Male vs. female independence test p value, effect size
MALE MEDIANS	Integrated	76.6 ± 0.177	76.2 to 76.9	0.00703, 0.216	p<0.001, 2.00
	Raw data	76.0 ± 0.00	76 to 76	0.00	not calculable[3]
FEMALE MEDIANS	Integrated	80.5 ± 1.20	78.6 to 82.6	0.161, p<0.001	-
	Raw data	79.9 ± 1.32	78 to 82	0.175, p<0.001	-
MALE MEANS	Integrated	76.7 ± 0.190	76.3 to 77.0	0.0184, p<0.001	p<0.001, 1.72
	Raw data	76.0 ± 0.200	75.6 to 76.3	0.0193, p<0.001	p<0.001, 1.74
FEMALE MEANS	Integrated	80.0 ± 1.08	78.4 to 81.9	0.146, p<0.001	
	Raw data	79.4 ± 1.09	77.7 to 81.3	0.148, p<0.001	-

Note. [1]Thin-plate spline integration or raw data. [2]Line of best fit (no assumptions made concerning linear model if *t* p not applicable); [3]not calculable: zero variance. Kendall p = Kendall rank correlation p value; -: value given in male row; S.D. = standard deviation; Column "global Mean" = mean over all cohorts. All values given to three significant figures (or range: integer or one decimal place).

Lastly, individual countries with most submitted data showed a slight male increase in interpolated-modal age for France (0.048 y/year) but a decrease for Italy (-0.069 y/year; Supplemental-files-S6,S7; Supplemental-Figs S5, S6) from cohorts 1880 to 1910 (gradients are small compared with females: 0.208 y/year). French male modal ages increased from 1816 (0.076 y/year; Supplemental-Fig-S6). However, small samples from individual countries are less likely to provide representative samples of "life-style" mortality for these periods (see discussion). Seven-country cohorts without French and Italian data gave similar results to nine-country cohorts (Supplemental-Figs-S1:S4).

DISCUSSION.

Cohort modes could be tracked over a period of 40 years with high-quality large European cohorts. From results it was clear that European male-bulk death-age modes were near-constant over the first ~30 years, in comparison to female increases (Fig 2; cohorts 1880 to ~1910; ignoring slight dips in male values also shown by residual plots; linear models not compared). Technically, conclusions regarding modes are independent of other distributional characteristics.

Male raw-median ages were exactly constant (at 76 y; integrated medians showing slight changes) for the 25 years available (cohorts 1880 to 1904), again in contrast to female increases (Fig 3A). Male means (Fig 3B) showed a slight increase (raw and integrated), possibly indicating the oldest older men were increasingly dying at older ages, as means are affected by extremes, whereas "bulks" were not necessarily affected.

This study has used some of the best techniques and only the highest quality data available to calculate cohort death-density modes using raw data or thin-plate splines. Other parameters could be used e.g. mortality rates, but we think dx' gives clarity. Thin-plate splines produce smooth surfaces infinitely differentiable with an interpretable energy function and no

manual tuning[9], but little difference was found between spline or raw data conclusions (sometimes splines did lesson irregularities).

There was some expectation that "rectangularization" [10] should occur (although this has been challenged [11]) and which did occur with females with modes moving to the right of distributions. Male cohort medians and means indicated "rectangularization" did not occur during these 25 years (but might return later).

Study limitations: (1) Although large datasets were analyzed giving smooth density distributions even without splines, larger studies could be made (perhaps using death rates). For many large countries e.g. the USA or China, life-table Lexis data were not available for the period studied, and caution is necessary to draw conclusions from other data types e.g. period data. We could not add data similar to that analyzed because, as far as we know, none exists. However, as the entire study was (non-independently) replicated using seven countries (with Italy and France removed; Supplemental-files-S8, S9; Figs S1:S4) with similar conclusions, it is safe to say conclusions apply at least to those pooled countries analyzed. (2) The nine countries contributed ~30% of the non-Russian/non-Ottoman European population[12]; conclusions do not necessarily apply to Europe as a whole, and further data curation is awaited. (3) Individual country data was not analyzed except French and Italian; although caution is needed for smaller sample sizes as raw-density distributions are more irregular (even shown by French/Italian cohorts), presumably reflecting increased random-event effects. (4) Although conclusions regarding modes are independent of population fraction (as long as modes are included), medians and means are affected by that analysed (here >60 y) and conclusions regarding these would change if another fraction were considered.

French male cohorts from 1816 showed a constant increase, which if extrapolated to ~1600 C.E. would give a 0 y mode (European data does not exist for this period). French data

also included the effects of wars, infectious diseases and dietary poverty and it is still possible therefore that life-style male mortality modes have fluctuated around 70-80 y for millenia even in France, but we simply do not know. Strictly speaking, it is impossible to know whether or not male results show underlying trends with perhaps constant periods followed by changes (hinted at in Introduction, although thought unlikely), or whether the constant period studied was exceptional. In the following we assume the male results from cohorts 1880 to 1910 were exceptional, and should have shadowed female increases, other aspects being equal, but didn't !

While there are many plausible reasons why male longevity should increase, and also many reasons why it might stagnate, it is intriguing that these almost cancelled over the period studied. Possibly males did not (or were unable to) take advantage of beneficial environmental changes. We can speculate that as prosperity increased, women thrived with better life-style choices, whereas males might have consumed more meat (see below) and alcohol, smoked, and become less active, all risk factors for an earlier death[13]. For the generation studied many had earlier fought in two wars, and effects of war (psychological/injury) might have resulted in behavioral or other effects.

Women are known to outlive men across high and low-income countries[14]. An Italian study has proposed that animal product consumption has significantly contributed to cardiovascular or cancerous diseases, with possibly greater negative effects in men than women[15]. Perhaps most importantly for 50-70 year olds, dramatic sex differences in U.K. cardiovascular disease deaths began ~1925, with male numbers increasing to ~1975, but female numbers decreased (see Figure 1 in [16]), and this might have also applied to Europe.[17] Quite possibly this increase in male-cardiovascular and other life-style disease frequencies contributed to male longevity stagnation. In the future, as more cohort bulks become measurable, male

central-moments-of-death ages might continue to increase due to the already measured fall in e.g. cardiovascular diseases.

In summary, there are many ways in which females might have responded to environmental changes during the first 30 years of the study period whereas the male bulk did not. Suspicion lies with changes connected with cardiovascular and other "life-style" diseases. It is a sobering thought, while still speculative, that a whole generation of men might in general not have taken (or been able to take) advantage of environmental changes for the opportunity for longer life. The fact that women live longer than men can now be supplemented by the knowledge that the bulk of women have been slowly living longer, whereas the ages of death for the bulk of European men (at least in some countries) were roughly constant for ~30 years, as measured by modal central tendencies, and only increased over the last ~10 years of the study period.

METHODS and METHODOLOGY.

Data sources.

High quality dx data was used from Cohort Life Tables from the Human Mortality Database (HMD; www.mortality.org, electronic access from 2015 to 2018, last download 09-11-2018; last checked 12-08-2019), to take advantage of the decisions made by experienced demographers (methods for extracting data, and dx calculations, were double-checked via email communication with HMD). Surprisingly, only few countries submit life-table cohort data, with many submitting period or other data for the study period (including e.g. USA, China). (Further high quality, large number data is apparently not available from other web sites.). Data from all available countries: Denmark, Finland, France, Iceland, Italy, Netherlands, Norway, Sweden and Switzerland, were

pooled for Analyses for each year over the entire period of study (source references in Supplemental files-S4,S5).

For each country, all HMD cohort life-table data for one sex (Age interval×Year interval: 1x1) were downloaded into a "country" (Excel 2007; Microsoft, Washington, USA) file; plus Births (Period) data. In each country file, HMD columns were removed except: "Year" (which means year of birth in HMD cohort sections; here changed to "Cohort"), "age" and "dx"; and an additional column added: "Year of death" (="Cohort"+"age"; 110+ as 110). Separate (Excel) files were created for each cohort (hereon meaning deaths of one sex born in one year), and filtered cohort data from each country file transposed into each cohort file; plus births. In a cohort file, for each country an additional row “Actual (numbers of) deaths” (dx’) was calculated by [dx values×births/100000 (the radix)] (This was checked against the summed "actual deaths" for each country cohort and found to be accurate). dx' values from each country were summed to give dx' values for a European cohort (combined in Supplemental-files-S1, S2). Similar procedures were used to create French male cohort files, from 1816 (Supplemental-file-S3).

Data from each cohort is for distinct individuals. Any (rare) missingness procedures were operated by HMD (www.mortality.org).

Periods of study.

Cohorts born from 1880-1919 (n=40). Cohorts were chosen with enough data so that modes of spline fits would not be affected by edge effects. The early-age and old-age borders were the ages with numbers of deaths 3/4 of numbers dying at the mode. (see below, and vertical lines in Fig 1). These borders were independent of the modal age; earlier cohorts were prohibited due to direct excess male deaths around the second world war and later cohorts through lack of data.

Means and medians could only be calculated for cohorts 1880 to 1904 because of lack of old age data for later cohorts.

Italy and France had provided data with the largest sample sizes, and male data for France (from 1816; Supplemental-file-S6, Fig S6) and Italy (from 1880; Supplemental-file-S7, Fig S5) onwards was also analyzed to assess possible effects of having smaller sample sizes. Additionally, the entire study was also carried out with data pooled from seven countries (without Italy and France).

Interpolation.

Interpolation was regarded as an important way to avoid abrupt changes found in the raw data (with the assumption that people die throughout the year, not just on one particular date !) and generally spline curve smoothing was noticeable even though each cohort had rather a large numbers of deaths recorded.

Coding for graphical and spline Analyses.

Cohort dx', and birth, data were transferred to coding files (Word 2007, Microsoft; Supplemental-files-S4:S9). For R function stability data zeros were changed to 1×10^{-2} (110+ y data kept in separate vector). Analyses used the R statistical platform (https://cran.r-project.org) and graphics software (Irfaview, www.irfanview.com; Designworks, Greenstreet Software, Huntingdon, UK). A broad plan of the coding follows: For one cohort, a thin-plate spline was fitted to the actual numbers of deaths (dx') from age 40 (or 1936 if later) to the oldest age (ages centered to +0.5y), using the R function *Tps* {fields}[1] with weights 1/dx' and lambda automatically found by generalized cross-validation. An interpolated modal age was found using *predict* {fields} and a 0.01 y grid to determine ages with 3/4 numbers of modal deaths (vertical lines in Fig 1). Cohorts without qualifying data between these limits were not analyzed (see above). Graphs of: numbers of deaths against age for each cohort, and averages against the date at which each cohort has 110 y, were drawn using *ggplot* {ggplot2} (see Figs 1:3). Raw medians and means were calculated for each cohort from age $\geq$60 y to 110+ (as 110) y. For each cohort the function *integrate* {stats},

using the same age range, estimated an "integrated" median by integrating successive 0.001 ages until half of the integral for the whole age range was reached, or an integrated mean by multiplying the integrals by age values and dividing by number of values. Integrals were checked graphically with raw data and percentages of raw numbers of death fractions (over births) were also plotted against cohort year at 110 y to emphasize the latest data available. (Non-graphical coding in each coding file is identical with only one part-string difference e.g. "MALE" or "fem".)

Statistics.

All statistics were carried out using the R statistical platform, using two-tailed tests. Most interpretation of results could rely on graphical visualization, but statistical comparisons between male and female data were also performed. Linear regressions for male:female comparisons would only be performed if the assumptions of normality of residuals, homoscedasticity, and linearity were met. The latter were ignored if residual standard error <1. Modal average data did not meet assumptions for linear regression, and only results from independence tests based on Kendall rank correlations are shown in the Tables. For all male:female comparisons a step-wise association test (to show if year steps were similar between male and female parameters) and an independence test were carried out using Kendall correlation coefficients. The latter followed conversion from Kendall's tau to Pearson's r, as in [2], which is probably conservative. All male/female comparison statistical results are given in Supplemental-data-file-S5, including effect sizes for linear regression and Kendall independence tests (using $r = Z/\sqrt{N}$). The alpha level for significance was set at 0.05.

Declarations.

Availability of data and material. All data, code and all calculations can be found in the Supplemental files and the Human Mortality Database (www.mortality.org). **Code availability.** All data and all calculations can be found in the Supplemental files. All residual plots can be generated using the coding Supplemental files. Correspondence and requests for materials should be addressed to JSCC. **Author contributions:** JSCC contributed to concept/design, data analysis/interpretation, statistical analysis, drafting the article; KR, KP, TW to data analysis/interpretation, statistical analyses, critical revision of article, TW, AC to critical revision of article. **Acknowledgments.** We would like to thank the Human Mortality Database staff for their help, the availability of data on their website at www.mortality.org. **Data and materials availability:** All data, code and all calculations can be found in the Supplemental files and the Human Mortality Database (www.mortality.org). **Competing interests.** The authors declare that there are no competing interests. **Ethics approval.** Not applicable. **Consent to participate.** Not applicable. **Consent for publication.** Not applicable. **Funding.** This study was funded entirely by the Pomeranian Medical University, Szczecin, Poland.

Supplementary Information is available for this paper.

References

Data source references: **required by the Human Mortality Database rules:**

Human Mortality Database: ; Denmark: [18,19]**; Finland:** [20]; **France:** [21–23]; **Iceland:** [24]**; Italy:** [25]; **Netherlands:** [26]; **Norway:** [27]**; Sweden:** [28]; **Switzerland:** [29]**.**

1. Cevenini E, Invidia L, Lescai F, et al. Human models of aging and longevity. Expert Opinion on Biological Therapy [Internet]. **2008**; 8(9):1393–1405. Available from: https://doi.org/10.1517/14712598.8.9.1393

2. Christensen K, Doblhammer G, Rau R, Vaupel JW. Ageing populations: the challenges ahead. Lancet [Internet]. **2009**; 374(9696):1196–1208. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2810516/

3. Seeman TE, Singer BH, Rowe JW, Horwitz RI, McEwen BS. Price of adaptation–allostatic load and its health consequences. MacArthur studies of successful aging. Archives of Internal Medicine. **1997**; 157(19):2259–2268.

4. Montagu JD. Length of life in the ancient world: a controlled study. Journal of the Royal Society of Medicine [Internet]. **1994**; 87(1):25–26. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1294277/

5. Carrieri MP, Serraino D. Longevity of popes and artists between the 13th and the 19th century. International Journal of Epidemiology [Internet]. **2005**; 34(6):1435–1436. Available from: https://academic.oup.com/ije/article/34/6/1435/707557

6. Lancaster HO. Expectations of Life: A Study in the Demography, Statistics, and History of World Mortality. Springer Science & Business Media; 2012.

7. Cummins N. Lifespans of the European Elite, 800–1800. The Journal of Economic History [Internet]. **2017**; 77(2):406–439. Available from: https://www.cambridge.org/core/journals/journal-of-economic-history/article/lifespans-of-the-european-elite-8001800/BE252C4B25C4AAC29ED62D591A1675AC

8. Beltrán-Sánchez H, Soneji S, Crimmins EM. Past, Present, and Future of Healthy Life Expectancy. Cold Spring Harbor Perspectives in Medicine [Internet]. **2015**; 5(11). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4632858/

9. Nychka D, Furrer R, Paige J, Sain S. Fields: Tools for spatial data [Internet]. Boulder, CO, USA: University Corporation for Atmospheric Research; 2017. Available from: www.image.ucar.edu/ nychka/Fields

10. Fries JF. Aging, natural death, and the compression of morbidity. The New England Journal of Medicine. **1980**; 303(3):130–135.

11. Wilmoth JR, Horiuchi S. Rectangularization revisited: Variability of age at death within human populations. Demography [Internet]. **1999**; 36(4):475–495. Available from: https://doi.org/10.2307/2648085

12. Wood J. The Nuttall Encyclopaedia. Frederick Warne & Co Ltd.; 1920.

13. Zheng Y, Li Y, Satija A, et al. Association of changes in red meat consumption with total and cause specific mortality among US women and men: two prospective cohort studies. BMJ [Internet]. **2019**; 365. Available from: https://www.bmj.com/content/365/bmj.l2110

14. Austad SN, Bartke A. Sex Differences in Longevity and in Responses to Anti-Aging Interventions: A Mini-Review. Gerontology. **2015**; 62(1):40–46.

15. Montesanto A, Rango F De, Pirazzini C, et al. Demographic, genetic and phenotypic characteristics of centenarians in Italy: Focus on gender differences. Mechanisms of Ageing and Development. **2017**; 165(Pt B):68–74.

16. Nikiforov SV, Mamaev VB. The development of sex differences in cardiovascular disease mortality: a historical perspective. American Journal of Public Health [Internet]. **1998**; 88(9):1348–1353. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1509070/

17. Mackenbach JP, Looman CW. Life expectancy and national income in Europe, 1900-2008: an update of Preston's analysis. International Journal of Epidemiology [Internet]. **2013**; 42(4):1100–1110. Available from: https://academic.oup.com/ije/article/42/4/1100/659306

18. Andreev K. Evolution of the Danish Population from 1835 to 2000. University Press of Southern Denmark; 2002.

19. Danmark Statistik. Befolkningens Bev\a egelser 1960–2000 [in Danish]. Copenhagen: Danmarks Statistik. **2001**; .

20. Statistics Finland. Population Structure 1878-2006 (annual series). Vol 6.

21. Bureau de la Statistique Generale des Postes et des Telegraphes Ministere du Commerce de L'Industrie. Annuaire Statistique de la France, Dix-Neuvieme. Tableau No 14 - Enfants nes vivants. [in French]. Volume, 1899. Paris: Imprimerie nationale.; 1899. p. P. 14.

22. Statistique Generale des Postes et des Telegraphes, Office du Travail, Ministere du Commerce de L'Industrie. Annuaire Statistique de la France. Tableau III Naissances suivant le sexe et la legitimite, Enfants declares vivants. [in French]. Vingtieme Volume, 1900. Paris: Imprimerie nationale.; 1901.

23. Vallin J, Mesle F. Tableau I-A-1: Naissances par sexe de 1899 a 1997 [in French]. Tables de mortalite francaises pour les XIXe et XXe siecles et projections pour le XXIe siecle. Paris: Instit national d'etudes demographiques.; 2001.

24. Jónsson G, Magnússon MS. Births, 1838-1950. Hagskinna. Icelandic Historical Statistics. [Internet]. Reykjavik: Statistical Bureau of Iceland; 1997. Available from: http://www.statice.is/

25. National File, Italy. 13th General Population and Housing Census, 20 October 1991. Chapter 2. [in Italian]. [Internet]. Istituto Nazionale di Statistica (ISTAT), Rome; 1929. Available from: http://demo.istat.it/index_e.html

26. Tabeau E. Mortality in the Netherlands: The data base. The Hague: Netherlands Interdisciplinary Demographic Institute; 1994.

27. Mamelund S-E. Cohort and Period Mortality in Norway 1846-1994 [Internet]. Oslo-Kongsvinger: Statistisk sentralbyrå . Statistics Norway, Oslo-Kongsvinger; 1996. Available from: http://www.academia.edu/23814911/Cohort_and_Period_Mortality_in_Norway_1846-1994

28. Statistisk årsbok för Sverige = Statistical yearbook of Sweden. Årg. 93 (2007) Årg. 93 (2007). Stockholm: Sveriges officialla statistik; Statistiska centralbyrån; 1751.

29. Federal Statistical Office. Two centuries of Swiss demographic history - Graphic album of the 1860-2050 period. [Internet]. 1998. Available from: https://www.bfs.admin.ch/bfs/en/home/statistics/catalogues-databases/publications.assetdetail.344341.html

30. Nychka D, Furrer R, Paige J, Sain S. Fields: Tools for spatial data [Internet]. Boulder, CO, USA: University Corporation for Atmospheric Research; 2017. doi:10.5065/D6W957CT

31. Walker D. JMASM9: Converting Kendall's Tau For Correlational Or Meta-Analytic Analyses. Journal of Modern Applied Statistical Methods. 2003;2. doi:10.22237/jmasm/1067646360

Figure legends.

Fig. 1. Death (dx') distributions, 1881. Deaths (estimated from dx) from male (a, x) and female (b, +) European cohorts, 1881 C.E.. Vertical lines show ages with numbers of deaths 3/4 of numbers dying at the mode. Curves show thin-plate spline fits (confidence intervals not shown but can be generated from supplemental files).

Fig. 2. Modal ages. Female (+; dashed line) and male (x) cohort modes from raw mortality (dx') data (a) or (b) interpolated modal ages from thin-plate spline fits, versus date (C.E.) at which cohort has 110 years.

Fig. 3. Cohort medians (a) and means (b). Female (+; dashed line) and male (x; solid line) cohort medians (a) or means (b) from raw mortality (dx') data, versus date (C.E.) at which cohort has 110 years.

Fig. 4. Percentage deaths at different age fractions. Numbers of cohort deaths (as percentages of total deaths) from raw data for: (1) ≥95 years old (y); solid triangles; (2) ≥60 to 76 y; solid

diamonds; (3) >76 y; empty diamonds; (4) >60 y; empty triangles; versus date (C.E.) at which cohort has 110 years.

Table legends.

Table 1. Male, female modal and gradient death-age parameters from raw data or thin-plate spline interpolation, across cohorts from 1880 to 1909 (n = 30) or to 1919 (n = 40).

Table 2. Male, female (≥ 60 y) median or mean death-age parameters from raw data or thin-plate splines.

Supplemental files:

S1_European_Female_dx_data.xls

Pooling calculations for European Female data from nine countries.

S2_European_Male_dx_data.xls

Pooling calculations for European Male data from nine countries.

S3_France_Male_dx_data.xls

dx' calculations for French Male data.

S4_Coding_European_Females.docx

Coding with European Female data from nine countries.

S5_Coding_European_Males.docx

Coding with European Male data from nine countries.

S6_Coding_France_Males.docx

Coding with French Male data.

S7_Coding_Italy_Males.docx

Coding with Italian Male data.

S8_Coding_EURMINUS_Females.docx

Coding with European Female data from seven countries.

S9_Coding_EURMINUS_Males.docx

Coding with European Male data from seven countries.

Supplemental Figure legends.

Supplementary Fig. S1 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S1. Seven countries. Death (dx') distributions, 1881. Data pooled from only seven countries. Deaths (estimated from dx) from male (a, x) and female (b, +) cohorts, 1881 C.E.. Vertical lines show ages with numbers of deaths 3/4 of numbers dying at the mode. Curves show thin-plate spline fits (confidence intervals not shown but can be generated from supplemental files).

Supplementary Fig. S2 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S2. Seven countries. Modal ages. Data pooled from only seven countries. Female (+; dashed line) and male (x) cohort modes from raw mortality (dx') data (a) or (b) interpolated modal ages from thin-plate spline fits, versus date (C.E.) at which cohort has 110 years.

Supplementary Fig. S3 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S3. Seven countries. Cohort medians (a) and means (b). Data pooled from only seven countries. Female (+; dashed line) and male (x; solid line) cohort medians (a) or means (b) from raw mortality (dx') data, versus date (C.E.) at which cohort has 110 years.

Supplementary Fig. S4 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S4. Seven countries. Percentage deaths at different age fractions. Data pooled from only seven countries. Numbers of cohort deaths (as percentages of total deaths) from raw data for: (1) ≥95 years old (y); solid triangles; (2) ≥60 to 76 y; solid diamonds; (3) >76 y; empty diamonds; (4) >60 y; empty triangles; versus date (C.E.) at which cohort has 110 years.

Supplementary Fig. S5 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S5. Italy. Modal ages. Italian male cohort modes (x) from raw mortality (dx') data versus date (C.E.) at which cohort has 110 years.

Supplementary Fig. S6 for article:

Title: Median/modal death ages of European males were near-constant for ~30 years.

Authors: Clark JSC, Rydzewska K, Podsiadło K, van de Wetering T, Ciechanowicz A

Fig. S6. France. Modal ages. French male cohort modes (x) from raw mortality (dx') data versus date (C.E.) at which cohort has 110 years: (a) cohorts 1816 to 1919; (b) region from 1880 to 1919 magnified.

Fig. 1. Death (dx') distributions, 1881. Deaths (estimated from dx) from male (a, x) and female (b, +) European cohorts, 1881 C.E.. Vertical lines show ages with numbers of deaths 3/4 of numbers dying at the mode. Curves show thin-plate spline fits (confidence intervals not shown but can be generated from supplemental files).

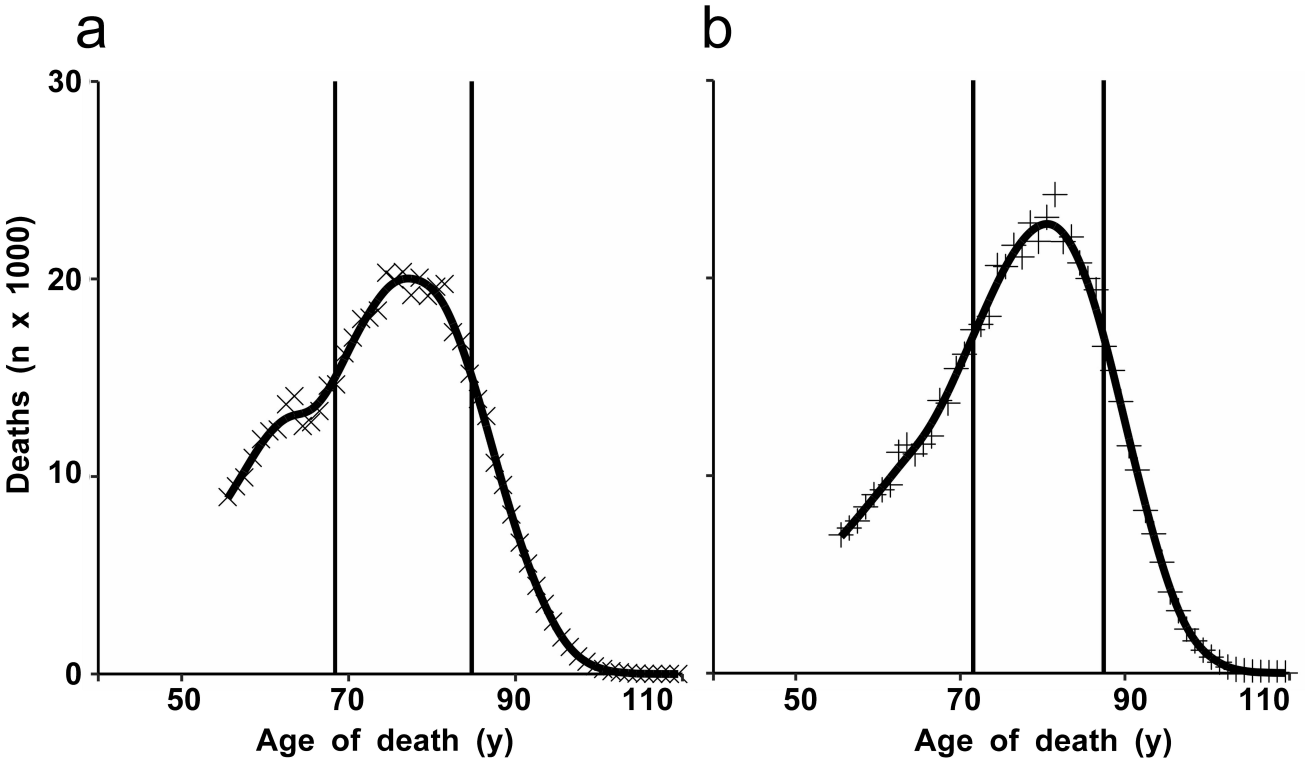


Fig. 2. Modal ages. Female (+; dashed line) and male (x) cohort modes from raw mortality (dx') data (a) or (b) interpolated modal ages from thin-plate spline fits, versus date (C.E.) at which cohort has 110 years.

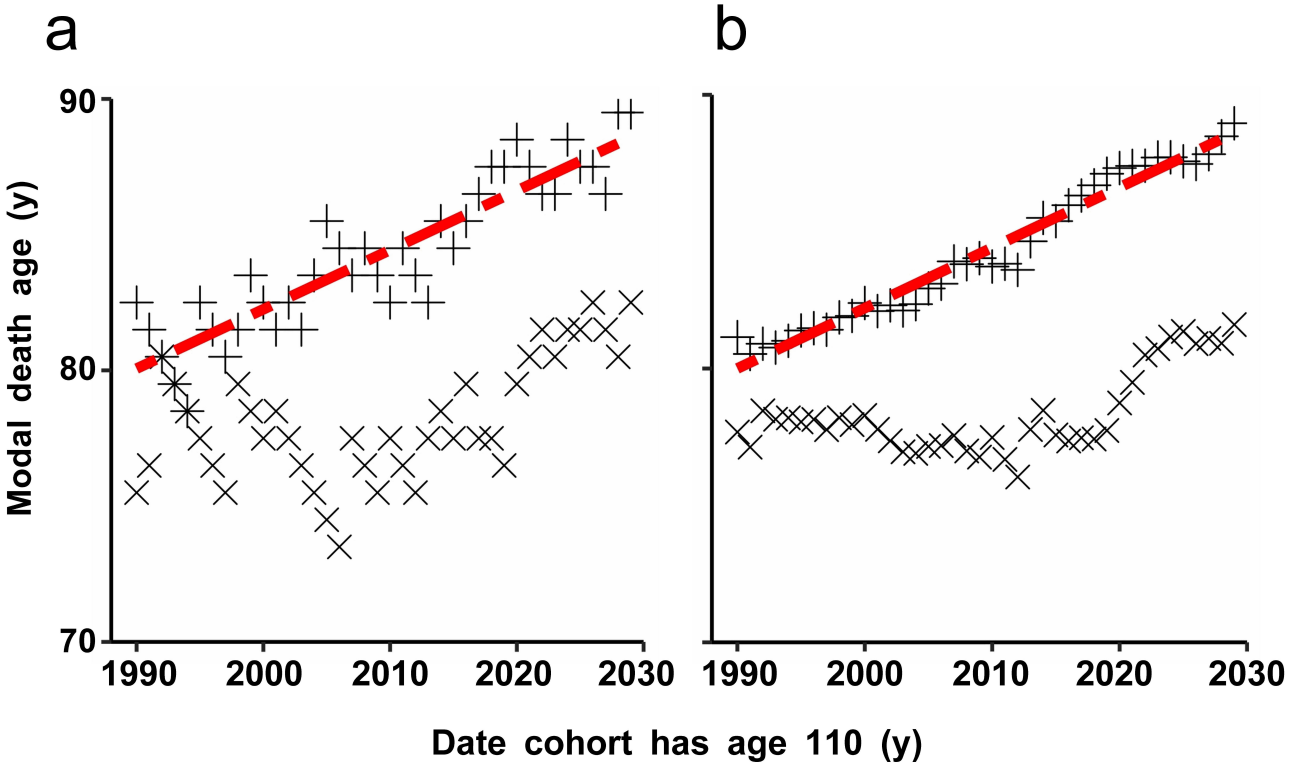
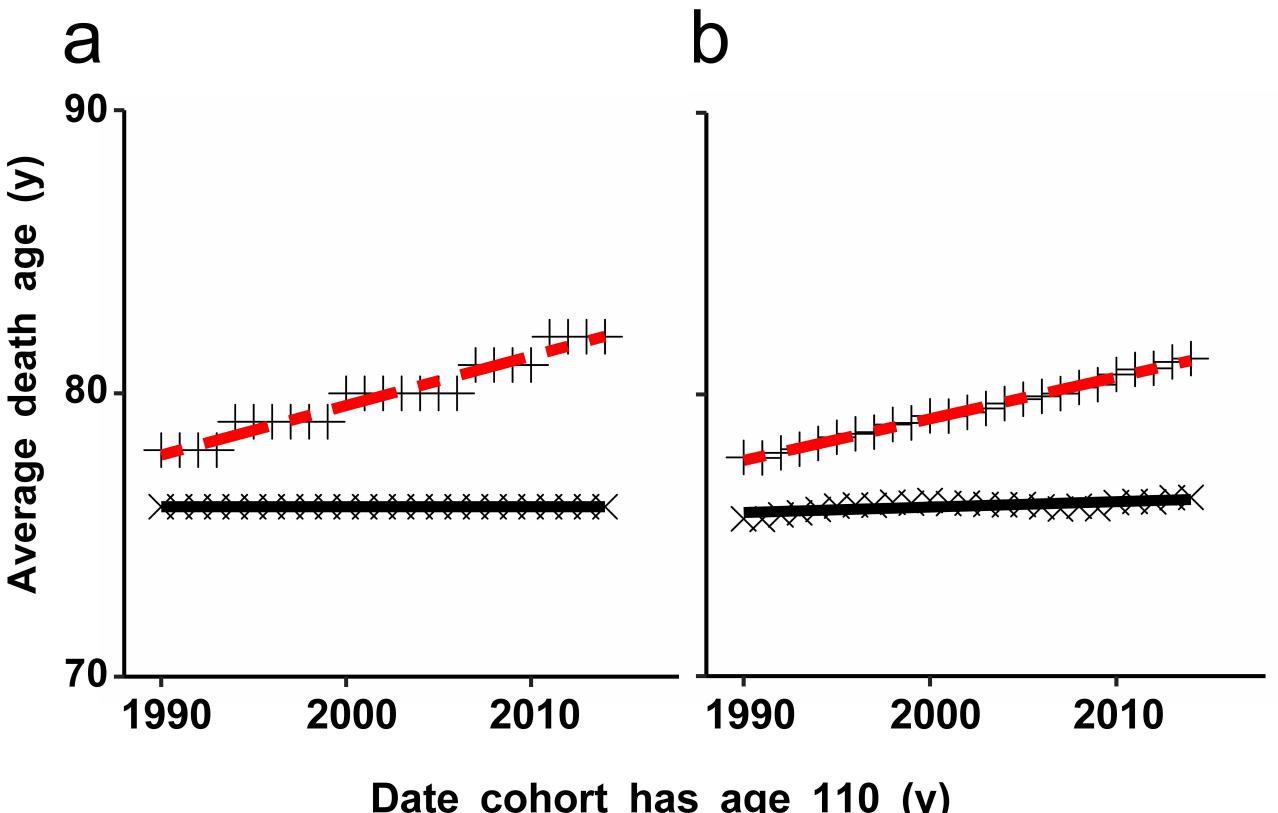
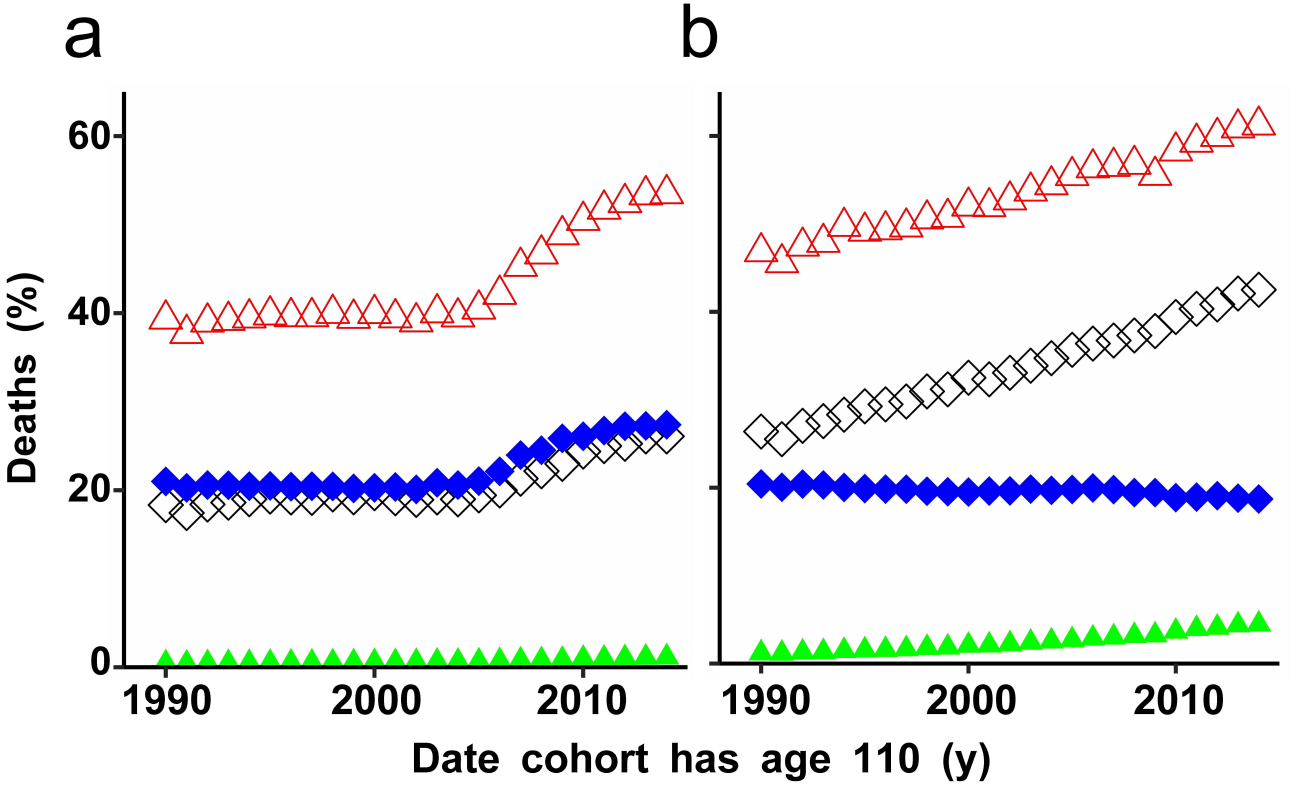


Fig. 3. Cohort medians (a) and means (b). Female (+; dashed line) and male (x; solid line) cohort medians (a) or means (b) from raw mortality (dx') data, versus date (C.E.) at which cohort has 110 years.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