Abstract submitted at the 2025 International Population Conference
Brisbane, Australia, 13-18 July 2025

Mortality above age 105. New data, new models

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September 2024

Abstract

Understanding mortality at extreme ages, such as 105 and older, is crucial for testing evolutionary theories on human longevity and aging, and for determining potential biological limits to human lifespan. However, accurately assessing mortality risks for this age group is challenging due to limited data, incomplete records, and unreliable age reporting. To address these issues, the International Database on Longevity provides validated mortality data for individuals aged 105 and older from 13 countries. This extended abstract presents preliminary findings based on updated data from France and outlines plans to compare these results with updated data from England & Wales. We employ both parametric and non-parametric models to refine the characterization of mortality patterns at extreme ages. Our findings indicate that the Gompertz model better describes mortality beyond age 105 compared to the exponential model, showing no evidence of a mortality plateau. Future analyses will investigate sex differences, cohort-specific mortality risks, and emerging time trends, while new non-parametric methods will be used to handle right truncation and fully utilize the dataset.

1 Background

Understanding mortality at extreme ages, here 105+, is crucial for several reasons. Firstly, it allows researchers to test evolutionary theories related to human longevity and aging. By examining how mortality patterns shift at the highest ages, we can gain insights into the biological and evolutionary factors influencing lifespan. Secondly, studying extreme age mortality helps determine whether there is a biological limit to human lifespan. This inquiry is fundamental for advancing our knowledge of the boundaries of human longevity and can inform future research and public health strategies.

However, the risks of death for individuals over age 105 remain notably uncertain due to several factors. The scarcity of observations is a significant issue, as the number of people reaching such advanced ages is limited, resulting in insufficient data for precise analysis. Additionally, the existing data often lack completeness, which can compromise the accuracy of mortality estimates. Compounding these challenges is the low reliability of reported age, where inaccuracies in age documentation can distort mortality statistics and further complicate our understanding of longevity at extreme ages.

To address these challenges and develop a scientifically robust dataset on mortality at extreme ages, an international consortium of researchers has dedicated over two decades to systematically collecting and validating data. Initially focused on documenting deaths of individuals aged 110 and older, the research efforts were later expanded to include those aged 105 to 109. This comprehensive dataset includes individual data on all deaths occurring within these age ranges across 13 countries with reliable civil registries. Each case has been subjected to a strict age validation procedure to ensure accuracy. This approach aims to build a more complete and precise picture of mortality at the highest ages. The resulting data, meticulously curated and validated, is now available as an open-access resource in the International Database on Longevity (2024, IDL, www.supercentenarians.org), providing valuable insights for ongoing research and analysis in the field of extreme age mortality.

Thanks to this extensive project, researchers are now able to monitor mortality at extreme ages across several low-mortality countries and have observed a significant increase in deaths among individuals over age 105 in recent years (Maier et al., 2010, 2021). This notable rise can be largely attributed to well-documented factors such as the substantial health advancements of the 20th century, which have allowed people from these generations to reach advanced ages.

Despite these advancements, obtaining new individual data remains challenging due to the growing stringency of privacy regulations, which are often overly restrictive. Nevertheless, recent updates to the dataset for two major countries, France and England & Wales, have provided a valuable foundation for further research. These updated data sets offer new opportunities for in-depth analysis and contribute to a better understanding of mortality trends at the highest ages.

In this abstract, we present preliminary findings related to France. We intend to expand our analysis to include both populations, aiming to conduct a comparative study of the mortality trends in France and England & Wales. Specifically, we will investigate whether the increase in the number of individuals aged 105 and older has occurred simultaneously in both populations, whether the sex ratios are comparable, and whether the probabilities of reaching age 105 are similar. Additionally, we will develop and apply new non-parametric models using the validated data to refine the characterization of the mortality curve at these advanced ages.

2 Data

Individual deaths occurred above age 105 will be extracted from the IDL for France (source: *Institut national de la statistique et des études économiques*, INSEE) and England & Wales (source: Office for National Statistics, ONS). As with all the countries in the IDL, the data have undergone a strict age validation procedure to check that the date of birth and identifying information on the death certificate are consistent with those on the birth certificate. This validation is applied exhaustively for deaths above 110 and on sample for deaths at 105-109 in both countries.

Figure 1 provides a comprehensive overview of the available mortality data for France with a Lexis diagram. The dataset encompasses a total of 14,467 deaths spanning the years 1978 to 2023, with a notable distribution across age groups: 98.8% of these deaths occurred among individuals aged 105 to 109 years, while 1.2% were among supercentenarians aged 110 and older. The gender distribution reveals a predominance of women, accounting for 91% of the cases, compared to 9% for men. The data covers cohorts born between 1870 and 1918.

3 Methods

Describing mortality at advanced ages can be accomplished by depicting death rates across age ranges, effectively assuming a piece-wise constant hazard model within each interval. A more refined depiction could be achieved by subdividing the age range into smaller intervals. However, in cases of limited sample sizes, such estimates can become highly erratic, making it difficult to draw conclusive findings. Furthermore, data concerning semi-supercentenarians exhibit truncation and censoring patterns, potentially stemming from sampling procedures in each country. These patterns must be taken into account when modeling the data, even in simple computations of death rates. In particular, to use the complete dataset effectively, right truncation is the critical issue that must be addressed. Right truncation occurs when an individual's data is only included in the analysis if the event of interest, here death, has already occurred by the time data are collected. Excluding individuals who are still alive but may eventually die after the observation period introduces bias, as the dataset no longer represents the entire population at risk.

In recent years, various methodologies have emerged aiming to provide a more concise representation of empirical data. Barbi et al. (2018) and Dang et al. (2023) have employed parametric models based on the proportional hazard assumption. Gbari et al. (2017) have proposed models grounded in extreme values theory. Gampe (2010) utilized an EM algorithm to model the force of mortality. In this study, we present two alternative approaches. First, following previous research, we employ a parametric

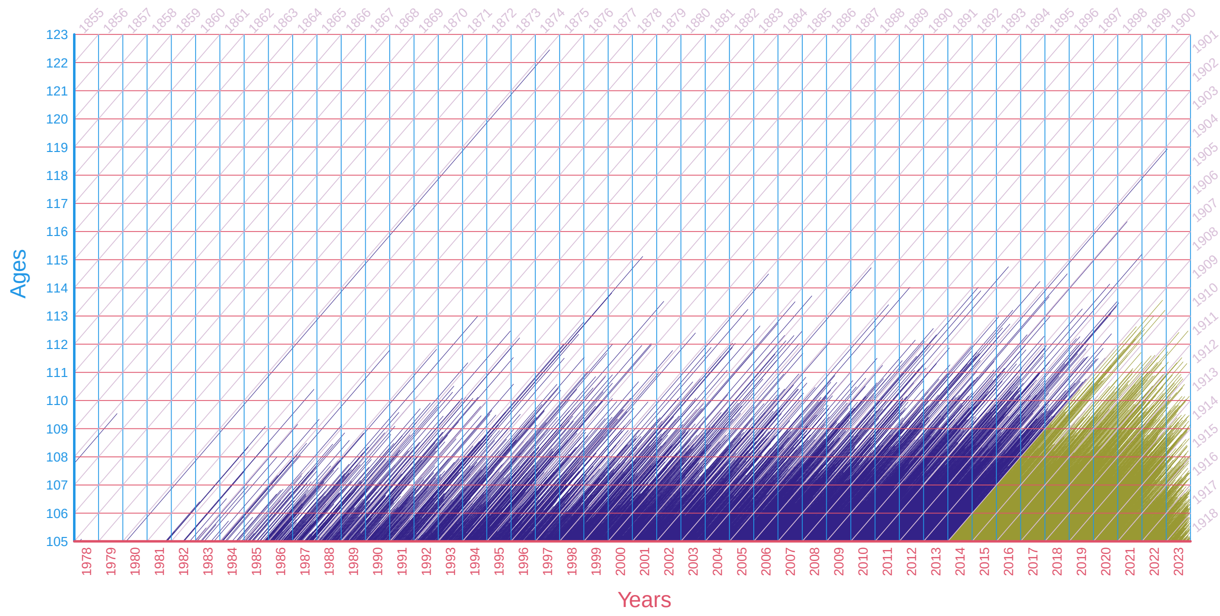

Figure 1: Lexis diagram depicting all recorded deaths in France for individuals aged 105 and older from 1978 to 2023. Individuals depicted in dark slate blue are assumed to belong to extinct cohorts in later analysis.

model that accounts for right truncation. Subsequently, we introduce a non-parametric method, as demonstrated in a simulated context by Camarda (2022).

While parametric approaches are well-documented in the literature, the non-parametric approach requires further explanation, albeit briefly in this abstract. In practice, this method involves dividing the age range into very small intervals and applying smoothness across ages by integrating a discrete penalty into the estimation process. This technique avoids imposing a specific structure on the underlying force of mortality and addresses common issues associated with piecewise constant hazard models, such as discontinuity and subjectivity in interval length. It also accommodates left truncation and right censoring and allows for the analytical computation of uncertainty. Additionally, prior information can be incorporated to either strengthen existing demographic knowledge or identify situations where the data does not provide insights into the underlying force of mortality. However, right truncation remains unaddressed by this approach. Consequently, our analysis using this approach currently focuses on extinct birth cohorts, tracking all members from age 105 until extinction (up to age 115 in this study). In Figure 1, this corresponds to using only the individuals represented by dark slate blue. In the coming months, we plan to integrate a method for handling right truncation within the non-parametric framework to utilize the full dataset.

4 Initial findings

In this section, we present a concise summary of the results, focusing solely on the observed lifespans of individuals. For the final version of the paper, we plan to perform a more comprehensive analysis, investigating potential sex differences in mortality patterns, assessing cohort-specific variations in mortality risk, and identifying any emerging time trends. Moreover, once the updated data from England & Wales is fully validated, we intend to perform a comparative analysis between these two populations.

Table 1 presents results from two widely used mortality models in this context: the exponential distribution, which assumes a constant mortality rate denoted by a, and the Gompertz model, which is defined by an initial mortality level a and an aging rate b. Notably, the constant hazard model is a special case of the Gompertz model, where the aging rate b is not significantly different from zero. To estimate the model parameters, we numerically maximized the likelihood, accounting for both left and right truncation. These results can be seen as an updated version of those presented in Dang et al. (2023). Consistent with this earlier study, we find that the Gompertz model more accurately describes mortality beyond age 105 in the French dataset, showing no evidence of the so-called mortality plateau. This conclusion is supported by confidence intervals for the parameter b that do not include zero, as well as by comparisons using the Akaike Information Criterion (AIC), which balances goodness of fit with model complexity. The Gompertz model clearly minimizes the AIC, reinforcing its superior fit.

Table 1: Estimated parameters for a constant hazard model (exponential distribution) and a Gompertz model, based on French deaths aged 105 and older from 1978 to 2023.

Model	Parameters	Estimates	95% CI	Log-likelihood	AIC
Constant hazard	a	0.6145	[0.6042, 0.6250]	-19795.56	39593.13
Gompertz	a	0.5760	[0.5621, 0.5903]	-19766.71	39537.42
	b	0.0499	[0.0381, 0.0618]		

Figure 2 displays the results from the smoothing approach outlined in Camarda (2022). Within this framework, we focus exclusively on extinct cohorts (1870-1909). Crucially, no predefined structure is imposed on the mortality law; instead, the data are allowed to reveal their own mortality patterns, which can vary across ages. While the amount of smoothing is determined using an objective criterion such as the AIC, the only choice made concerns the order of differences in the penalized term of the estimation procedure. We present both first-order and second-order differences, which can be interpreted as the prior information provided to the model when the data lacks sufficient strength to fully guide the estimated hazard. Specifically, first- and second-order differences indicates a constant and a Gompertz hazard, respectively.

In our example, the estimated smooth curves for the two orders of differences in Figure 2 are quite similar, particularly for ages below 110, indicating a strong signal from the data for that pattern. Beyond this age, there is a slight discrepancy between the two hazard estimates, suggesting that the prior knowledge imposed by the order of differences may influence the results. However, the 95% confidence intervals largely overlap, indicating that final conclusions should be approached with caution at very high ages.

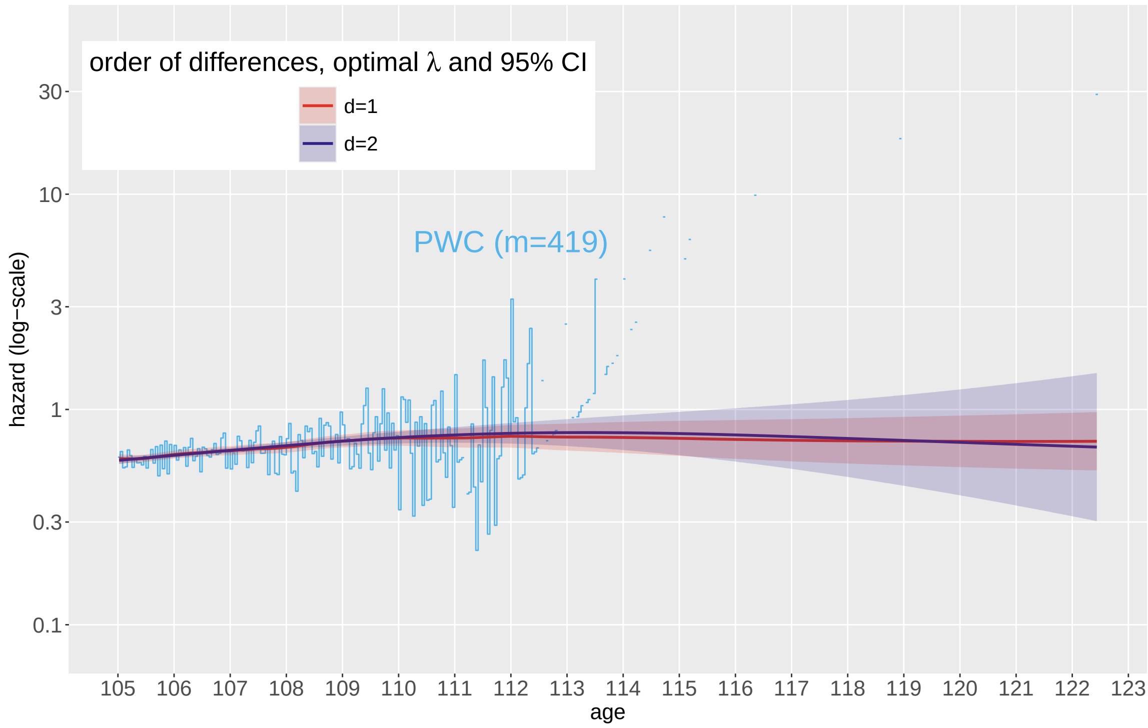

Figure 2: Smoothed estimated log-mortality from a penalized piecewise hazard model. French deaths aged 105 and older from the 1870-1909 cohorts. The step function in light azure depicts the associated (and unpenalized) piecewise constant hazard (i.e., death rates) computed for each two-week interval.

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