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Applying the Pace and Shape Approach of Aging

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Abstract

The studies aims to illustrate the various applications of the *"Pace and Shape of Aging"* — a novel two dimensional approach decomposing mortality in timing and magnitude. After an introduction of the fundamentals of this approach, we present the results of a pace-shape analysis on human mortality development, interspecies mortality differences and an investigation of the aging patterns of human causes of death.

Aging patterns are diverse across the tree of life. Generally, aging patterns are described by fertility and mortality. This study only focuses on mortality characteristics. With respect to mortality, three fundamental types of aging can be distinguished (Baudisch and Vaupel, 2012). These are negative senescence reflected in a decrease of mortality over age, negligible senescence reflected in an approximately constant intensity of mortality over age, and senescence reflected in an increasing mortality pattern, as illustrated in the left-hand graph of Figure 1. These trajectories reveal the "shape of aging", i.e. whether organisms get better, sustain a certain state or get worse over their life course, notably so independent of their length of life. Life-expectancy in each of the three scenarios a priory could be long or short - it depends on the level of mortality. The level of mortality sets the speed at which the clock of life ticks away, independently of whether mortality falls, stays level or rises. Baudisch argues that the "pace" of life needs to be distinguished from the "shape" of aging (Baudisch, 2011). Distinguishing between pace and shape has been demonstrated to change our conclusions about the strength of aging (for a detailed explanation see: Baudisch, 2011; Jones et al., 2014). To eliminate the confounding effect of time, and to reveal the shape of aging, Baudisch (2011) suggested to pace-standardize age and mortality, utilizing life-expectancy as a measure of pace[1]. Standardized age can be calculated as

$$x_s = \frac{x}{e_0}.$$

[1] for a detailed analysis of pace-standardization and pace measures see: Wrycza and Baudisch (2014)

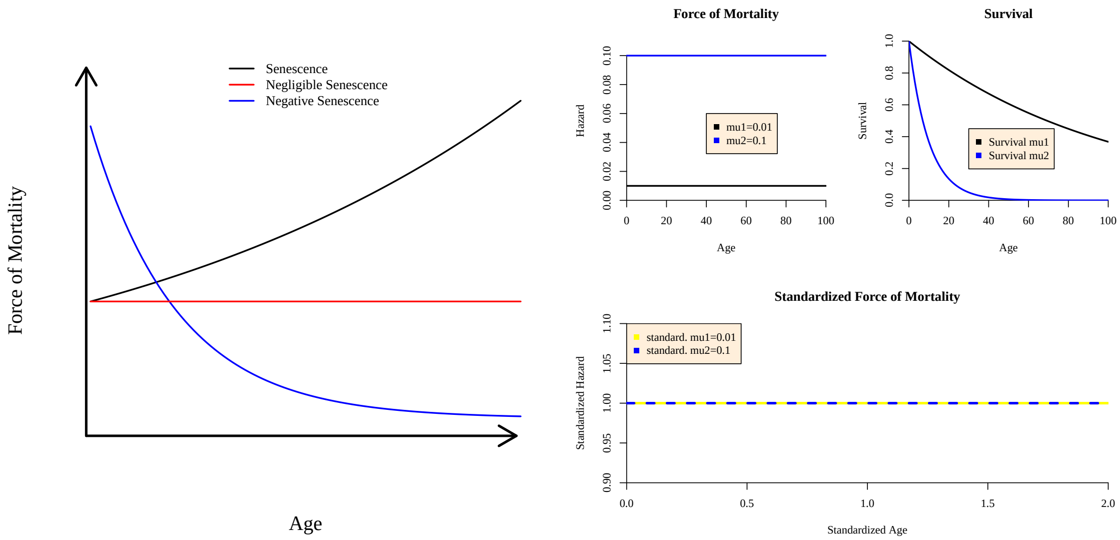

Figure 1: Three types of Aging and an Example of the Application of Pace and Shape

Standardized age one, $x_s = 1$, corresponds to the exact unstandardized average age at death, e_0. The standardized force of mortality derives from the unstandardized mortality pattern via multiplication with the pace value, which corresponds to dividing by the average hazard of death:

$$\mu_s(x_s) = e_0 \cdot \mu(x) = \frac{\mu(x)}{\bar{\mu}}.$$

Values of standardized mortality above one mark ages when mortality lies above its average, values below mark ages of less than average mortality. When $\mu_s(x_s) = 1$ then $\mu(x) = \bar{\mu}$. The right-hand graph in Figure 1 illustrates the application of the pace-shape approach to two artificial populations with negligible senescence that solely differ in the pace of life. Using real data, human mortality development serves as another valuable example for populations where mortality increases with age. Figure 2 depicts the development of human mortality before and after pace-standardization from hunter gatherer populations over historical populations to modern populations, utilizing the Gompertz mortality model. Historical and modern Data are given for French females between 1751 and 2010. Hunter-gatherer parameters are taken from Gurven and Kaplan (2007) and are included to provide an evolutionary context for the historical development of the shape of aging for humans.

The figure highlights the dramatic increase in the human shape of aging, especially in the 20th century. In low mortality countries, nowadays humans suffer exceptional high levels of senescence. This finding is remarkable considering the relatively slow pace of aging (i.e. high life expectancy) that humans experience in contrast to hunter-gatherer populations.

Modern French females experience a steep shape of aging. In numbers, for French females aged 1.3 standardized age, mortality is 35 times higher than average mortality in this period. In comparison, mortality at the same age in 1950 is only 13 times higher than the corresponding average.

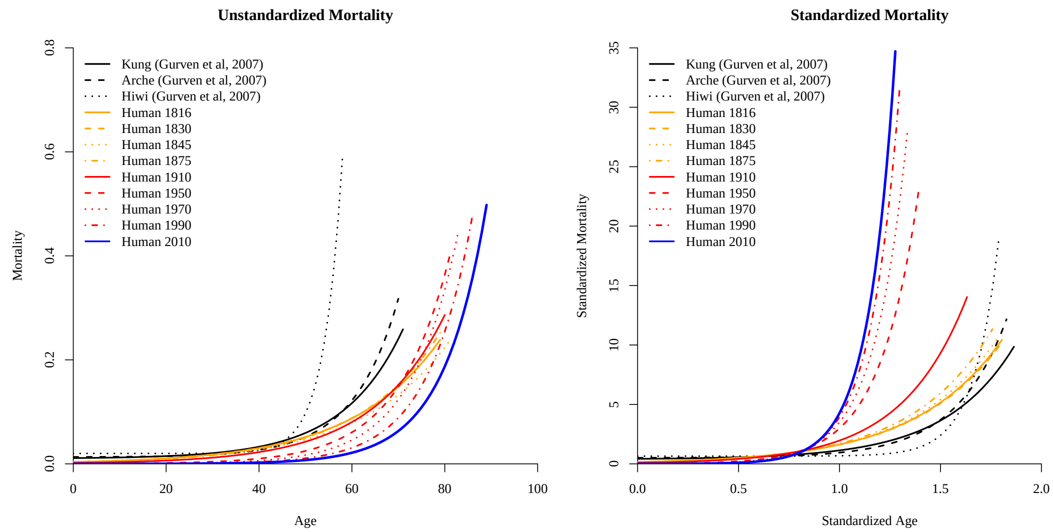

Figure 2: Unstandardized and Standardized Human Forces of Mortality, French Females, 1816–2010 and three Hunter Gatherer Populations (Gurven and Kaplan, 2007)

Along with this development, mortality is compressed into a narrower age range on the standardized age scale. This is due to the comparatively small variability of the age at death in human populations.

In this study, we demonstrate the utility of the pace and shape framework of aging for demographers by means of two examples. 1) We conduct an interspecies mortality comparison and 2) utilize the pace-shape framework to analyze the aging patterns in human causes of death. In doing so, we use the pace-shape space, a central tool in the novel framework.

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