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Pace and Shape of Causes of Death

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Abstract

Humans have experienced remarkable mortality changes, paralleled by a shift in leading causes of death. This development resulted in exceptionally high levels of senescence. The question arises: how do specific causes of death shape the human aging pattern? To evaluate the relation between causes of death and the pattern of aging, we present a new method applying the recently developed framework of the "pace and shape of aging". This approach disentangles the pace of life from the qualitative, pace-standardized pattern (or shape) of aging. Based on US data from 1959 to 2010, we define three criteria to quantify 1) whether specific causes are more or less senescence related, 2) whether they have an accelerating or decelerating effect on aging, and 3) whether they are more or less alterable. We utilize the "pace-shape-space" as a novel tool to summarize demographic information without need for parametric modeling, visualizing results along only two axes.

1 Background

The main drivers of longevity extension have changed over time. Declining infant and early adult mortality drove progress until the late 1940s, whereas older and old age mortality have been fueling progress since the 1950s. This shift in age-contributions to longevity increase has been paralleled by unprecedented changes in the human pattern of senescence, where senescence is defined as an increase in mortality over age.

Changes are also pronounced in the cause of death distribution. Infectious and parasitic diseases have been supplanted by chronic diseases like neoplasms and cardiovascular diseases (Omran, 1971). However, since the 1950s, these causes have undergone significant alterations as well (Vallin and Meslé, 2004). The underlying mortality dynamics together with the progress against certain causes of death report a continuing alteration of the general human aging pattern. Cause of death can play an important role in the investigation of these changes because they contain, besides information on mortality dynamics, valuable insights into physiological aging processes accompanying the human life course. Thus, we ask, how are causes of death linked to the human aging pattern?

2 Objective

Overall and cause-specific mortality development has drawn the attention of demographers and biologists to the age-associated nature of causes of death. Different approaches have been applied to evaluate cause specific aging patterns. Approaches can roughly be distinguished in frameworks based on a theoretical extrinsic-intrinsic partition (cf. Abrams, 2004; Bongaarts, 2005; Carnes et al., 2006), and more empirical approaches which utilize mortality increase and prevalence as indicators (cf. Horiuchi, 2006; Horiuchi et al., 2003; Horiuchi and Wilmoth, 1997).

Considering the theoretical approaches, it is difficult to disentangle extrinsic-intrinsic mortality because death inevitably comes about by an interplay of internal state and external environment. Death can be more or less successfully avoided depending on internal state, and a certain internal state may only lead to death given a certain environment, or the lack thereof (Wensink et al., 2014). Also the empirical based studies are facing problems. These studies measure and compare along the absolute chronological age-axis which can result in misleading outcomes. In view of the tremendous increase of our life span, the meaning of age has changed rapidly. Burger et al. (2012) demonstrate that the colloquial expression ”40 is the new 30” is more than just a mere saying. It reflects solid empicially observed truth. In fact, Japanese people around age 70 today could be considered just as young as hunter gatherers in their late teenage years, at least by judging from ages of similar mortality experience (”equivalent age”). What means “young” and what means “old” is relative and only makes sense given a certain context. This applies also for causes of death. Table

	Mean Time to Death at Age 15			
Cause of Death	1960	1975	1990	2010
Suicide & Intentional Self-Harm	38.92	34.43	35.91	35.89
Neoplasms of Larynx, Traches, Bronchus and Lung	50.29	52.28	55.06	59.36
Diabetes Mellitus	55.55	58.88	60.12	62.13
Ischaemic Heart Disease	59.71	62.31	64.85	67.05
Influenza & Pneumonia	61.15	64.91	69.22	69.55
Dementia and Alzheimer’s Disease	64.54	62.70	70.36	73.56

Table 1: Mean Time to Death at Age 15, Selected Causes of Death, Total, USA

1 illustrates that also causes of death operate on different time-scales and additionally, these scales experience a change over time. For instance, the mean age of death for neoplasms of larynx, traches, bronchus and lung is around 6.5 years lower than those of the ischaemic heart disease in 2010. The gap becomes even bigger if we compare, for instance, suicide and diabetes or influenza and pneumonia with neoplasms. Thus, we need to consider the relative meaning of age when we are investigating and comparing cause-specific aging.

To fulfill the demand of a comparative framework, we are aiming to provide a new method that links cause-specific aging patterns to the general human pattern which is, thereby, accounting for

the relative meaning of age and time. Our approach is purely demographic, i.e. based on the pattern of mortality. By interpreting all-cause indicators as weighted averages of a mixture distribution, whose components are causes of death, we utilize the "pace and shape of aging" to link cause-specific and general patterns (Baudisch, 2011). Based on explicit criteria, we classify causes by pace and by shape separately and their influence on the changing human mortality profile.
Our approach provides a novel tool to concisely summarize complex demographic information without the need for parametric modeling, visualizing results along only two axes.

3 Methods

Recent research has shown that conclusions about the strength of aging can change significantly when new measures of aging – the *pace of life* and the *shape of aging* – are disentangled (Baudisch, 2011; Jones et al., 2014). Accordingly, pace measures how fast the death clock ticks away and shape captures how mortality changes over the life course, standardized by its average length, i.e. pace (Baudisch, 2011). Figure 1 illustrates the basics of the pace-shape framework. The left panel depicts

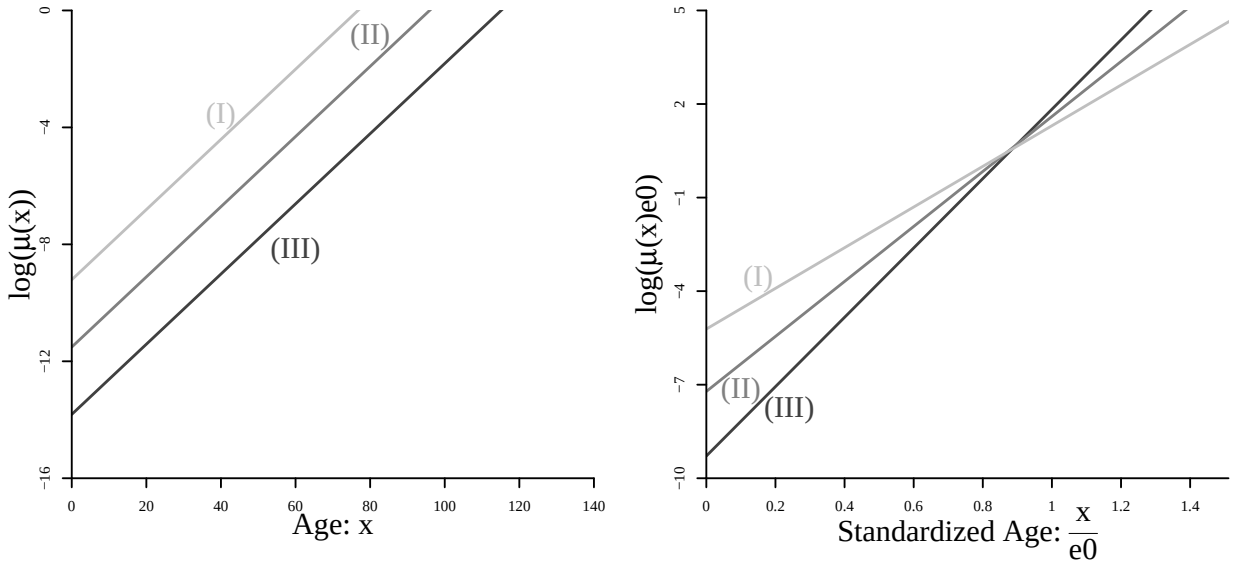

Figure 1: **Un-Standardized (left panel) vs. Standardized Perspective (right panel) on Mortality Trajectories: The graphs are based on Gompertz-Mortality-Models. All artificial forces of mortality have the same rate of aging but the starting level of mortality varies.**

the un-standardized perspective. Since senescence is defined, in a purely quantitative way, as increase of mortality over age, all trajectories are following this pattern. In terms of senescence levels, no differences can be identified since the rate of aging is the same for all examples. Thus, we would conclude all three patterns experience the same strength of senescence.
In fact, the development of senescence is difficult to judge from the left panel because pace and shape are still intertwined. Mean ages at death are 54.33 (I), 73.47 (II) and 92.65 (III), respectively.

Thus, we are confronted with the ambiguous effect of age in the evaluation of aging in a comparative framework. Applying a pace-standardization with standardized age calculated as

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

where e_0 denotes life expectancy at the first age considered (e.g. birth or maturity), and standardized mortality derives from

$$\mu(x_s) = e_0 \cdot \mu(x) = \frac{\mu(x)}{\overline{\mu}}$$

where $\overline{\mu}$ denotes average mortality over age, leads to the graphs in the right panel of Figure 1. Here, the three examples reveal visible differences identifying pattern (III) as the trajectory with the strongest increase and, therefore, with the highest level of senescence.

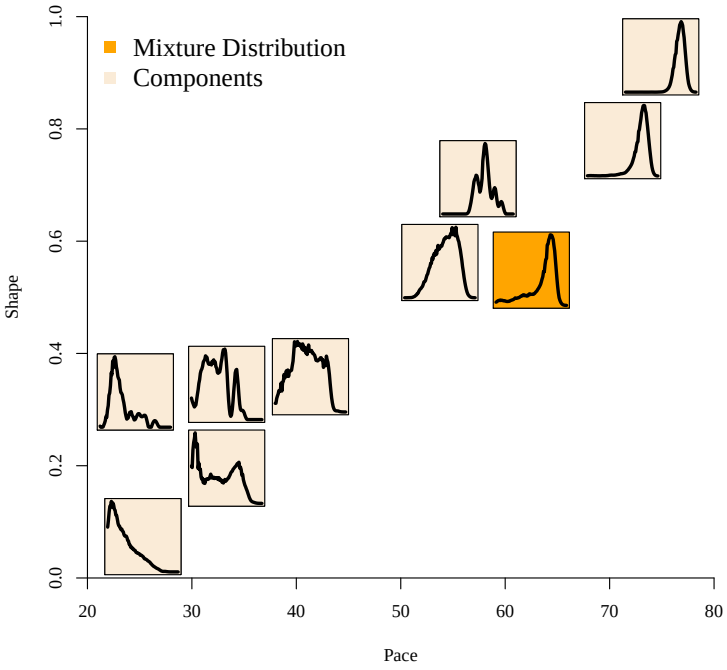

Figure 2: **Pace-Shape Space with Artifical Life Span Distributions: All distributions are plotted along the same time axis; each distribution is normalized, such that the area under the curve equals one.**

However, Figure 1 is only an illustrative example of the application of the "pace and shape of aging". Since our goal is to compare and link cause-specific and all-cause aging pattern across time, we are confronted by a huge number of trajectories. Hence, a systematic analysis requires a comparative framework which concisely summarizes the complex demographic information. To fulfill the demand for compact measurement, the pace-shape framework relies on the attribution of a scalar via appropriate measures for pace and shape respectively. Wrycza et al. (2014) and Wrycza and Baudisch (2014) examines possible measures for both dimensions. Accordingly, pace is measured

as adult life expectancy and shape is evaluated based on a re-scaled variant of the coefficient of variation (Wrycza et al., 2014).
By applying these measure, each cause of death can be classified assigning two scalar values for pace and shape respectively. This enables depicting the causes in a scatter plot. The plot concisely summarizes cause-specific characteristics with respect to both dimensions. To illustrate the approach, figure 2 exemplifies such a "Pace-Shape Space" for an artificial population with artificial causes of death that resemble typical components of the human life span distribution. The graph depicts the mixture distribution of causes, representing the total population marked in orange, along with its associated sub-population, each representing a certain cause of death. All distributions are located at the coordinates given by their respective pace and shape values.

4 Data

The analysis is based on data from the Human Mortality Database (2014) and for the years 1959 to 2010, a reconstructed time series of cause of death in the USA based on vital statistics of the National Center of Health Statistics (National Bureau of Economic Research, 2014). The cause of death coding comprises 23 different causes.
The cause-specific pace and shape values are calculated based on normalized cause-specific life tables which are obtained using a multiple-decrement approach (cf. Preston et al., 2001).

5 Preliminary Results

The analysis of cause-specific patterns is based on criteria considering pace, shape and the time trend gradient of both. Note the criteria hinge on a given benchmark population, they are only valid relative to a reference group given by the mixture distribution of all-cause mortality.
Higher (lower) shape values compared to all-cause mortality mark more (less) senescence related causes of death. Higher (lower) pace values compared to all-cause mortality mark decelerated (accelerated) cause of death. The time trend gradient marks whether causes have exceeded, developed simultaneously or lagged behind the change of all-cause pace and shape over time.
Figure 3 depicts six pace-shape spaces for different causes of death for females. Considering pace, for instance, ischaemic heart disease and dementia together with Alzheimer's Disease have a slower than average pace, meaning higher mean ages, over the entire period. Neoplasms of the breast and suicide reveal faster paces and thus, both cause groups have an accelerating effect on total pace.
Considering shape, the ischaemic heart disease is more-senescence related, whereas neoplasms of the breast are less-senescent. Thus and opposite to ischaemic heart disease, breast cancer pulls all-cause senescence levels down.
Septicaemia, influenza & pneumonia as well as dementia and Alzheimer's disease show changes in pace and shape, which exceed the overall development. In contrast, neoplasms of the breast show a time trend gradient for both dimensions similar to those of the all-cause pattern.

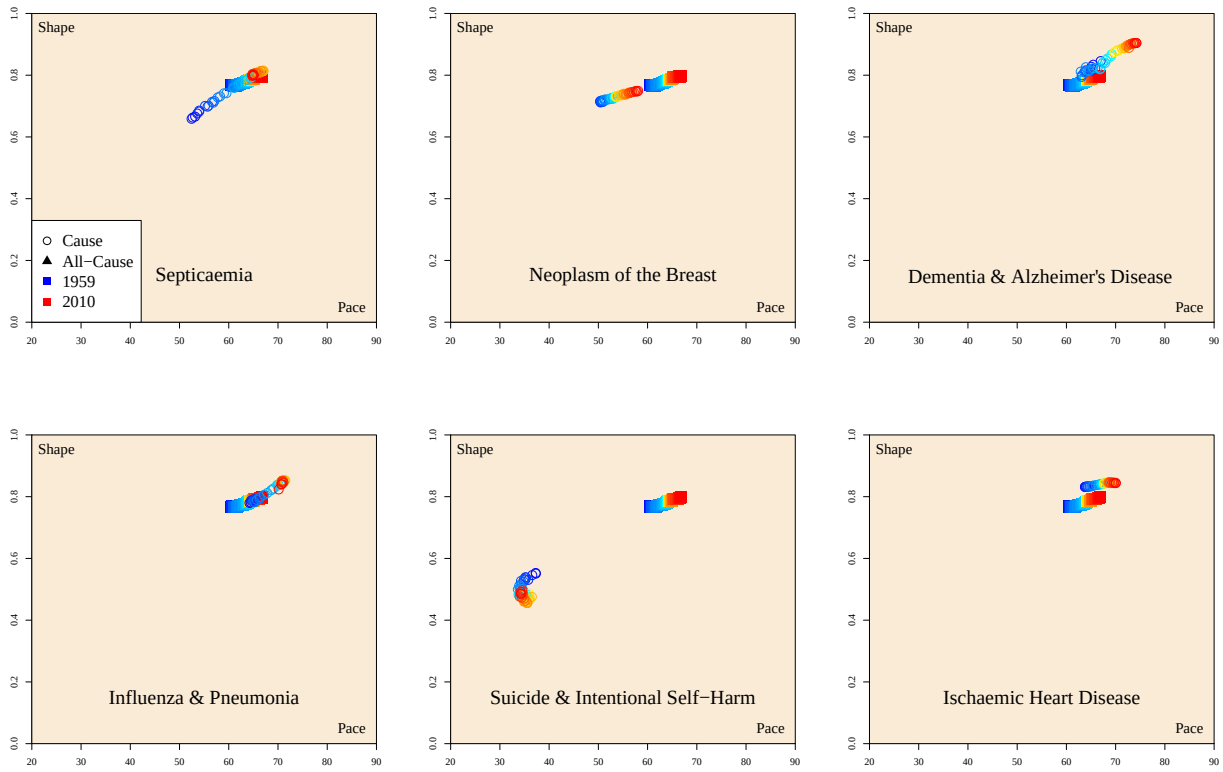

Figure 3: **"Pace-Shape Spaces", US Females, 1959-2010: The graphs depict six causes of death and the all-cause pattern. The pace-shape space follows the idea of a scatterplot. It illustrates the respective pace and shape combinations of each cause of death.**

A further step in the analysis is the consideration of the importance of each cause of death for all-cause mortality to visualize the forces driving and braking the change of the human aging pattern .

6 Conclusion

The meaning of age is relative across causes of death. Disentangling pace from shape accounts for the changing meaning of age. Our proposed approach provides a new and dynamic perspective on causes of death and how they are linked to the all-cause aging pattern. The explicit criteria, corresponding to cause-specific pace and shape characteristics, provide a solid basis for the evaluation of the linkage between the cause-specific and all-cause aging characteristics. The influences of causes of death on the all-cause aging pattern are diverse. Across time, cause-specific pace and shape alterability provides evidence for a different importance of pace and shape for specific causes and their contribution to the all-cause development.

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