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THEORETICAL AND EVOLUTIONARY BIOLOGY

Historical Stability of the Human Aging Rate and Its Decline in Our Time

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Abstract—It was found that changes in the mortality rate with age, minus the background constant of the Gompertz–Makeham formula, the increment in the mortality rate, as well as the exponential coefficient of this formula, reflect the actual rate of human aging. Using age-related mortality data for 40 countries, it is shown that the rate of aging does not change significantly over history and is almost the same for different countries from the mid-18th to the mid-20th century. It was noted that its linear growth persists (on a logarithmic scale), starting from the end of the period of development and growth of the body until the age of centenarians, when the speed of aging is reduced (due to the inherited longevity of the population). However, since the mid-20th century for the first time in history, slowing of the rate of aging in all parameters, including maximum life span, which is apparently associated with pronounced success in the economy and in health and social care, has been noted.

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INTRODUCTION

The duration of life and the rate of aging of a person are stable species (physiological) constants, the possibility of changing which is of considerable scientific and practical interest. A number of topics related to the nature of aging and the interpretation of methods for its quantification continue to be the focus of attention: the possibility of the existence of biological limits to the human life span (LS) (Dong et al., 2016; Lenart and Vaupel, 2017); change throughout history and for different countries in the rate of aging; changes in the rate of aging throughout life, including a possible decrease in the rate of aging at the ages of centenarians; increase in the maximum LS (De Beer et al., 2017; Barbi et al., 2018), etc. Does a uniform exponential increase in mortality persist throughout life or does it decrease at the age of centenarians, reaching a plateau (Barbi et al., 2018)?

For many specialists, analysis of age-related mortality has been the main method of studying aging since the time of Gompertz's studies (Gompertz, 1825).

The aim of this work is to study age-related changes in the rate of aging using data on the historical age-related mortality for a number of countries in the world.

MATERIALS AND METHODS

Age-related mortality was studied in 40 countries from 1750 to 2014 using data from the Human Mortality Database (http://www.mortality.org, accessed January 25, 2019). The survival tables for a cohort of 100000 were examined for one-year mortality data with historical ten-year periods. For data processing, we used the standard Microsoft Office Excel program, as well as the program "Population aging" specially developed by us (Dontsov, 2019).

Graphs of changes in the overall age-specific mortality rate (m) and its increments ($d(m)$) for neighboring ages were plotted on a logarithmic scale for the ages 1–110 years with ten-year intervals in history, and then the indices of the Gompertz–Makeham formula were calculated using the well-known methods described by Gavrilov and Gavrilova (Gavrilov, Gavrilova, 1991): $m = A + R_0 \exp(kt)$, where A is a constant, an indicator of external influences on mortality; R_0 and k are the coefficients that are considered to reflect the biological nature of mortality, i.e., aging itself: R_0 is the initial level of population aging and k is the rate of change of aging. Index $d(m)$ is the increment in the intensity of mortality per year, which excludes the constant A; i.e., it also reflects the actual aging rate. The true mortality rate was compared with that calculated using the parameters of the Gompertz–Makeham formula, and the correlation coefficient was calculated (r).

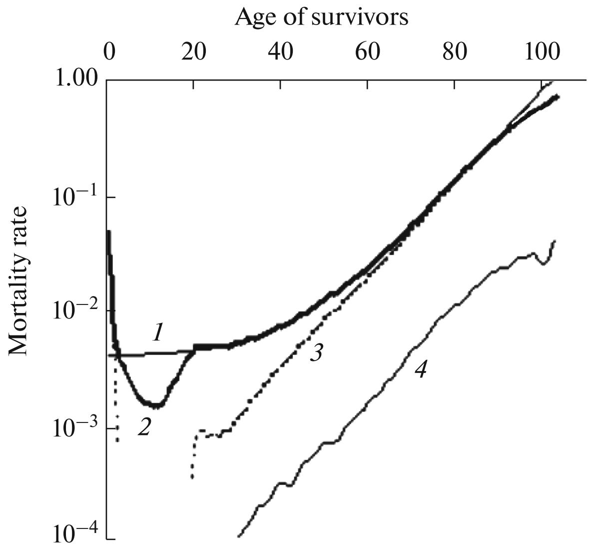

Fig. 1. Changes in the intensity of mortality and rate of aging with age, France, 1930. Calculated mortality intensity curve (*1*), the real curve *m* (*2*), the biological component of the mortality rate *m–A* (*3*), and the increase in mortality intensity *d*(*m*), linear three-point smoothing (*4*).

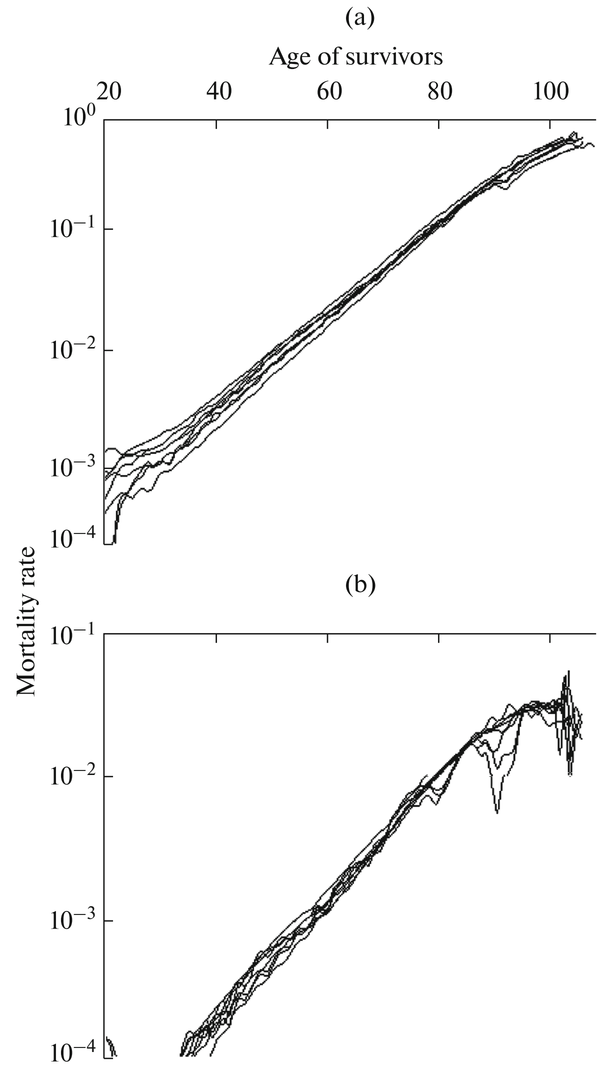

Fig. 2. Aging rate in different countries. (a) Mortality without a background component (*m–A*), (b) increment in mortality intensity (*d*(*m*)); for Australia, Belgium, France, the Czech Republic, Portugal, Spain, Sweden, and Finland, 1950.

The maximum and average life expectancires were also taken into account.

RESULTS

The Gompertz–Makeham plots for a number of countries in history show abrupt changes in the form of charts and formula coefficients; at the same time, the straight-line form of the graph is usually maintained only in the 50- to 70-year age period (Fig. 1, for example, France, 1930). However, the use of graphs of mortality rates minus the external component of mortality (*m–A*) and graphs of the increment of mortality intensity (*d*(*m*)) shows that the linear shape of the graph (on a logarithmic scale) from the period of the end of growth and development is preserved: the patterns of changes in the aging process remain the same, despite the pronounced changes in the graphs of the total intensity of mortality.

The superposition of several curves reflecting the actual aging rate shows that it is practically the same for different countries as it is for the change in the indicator *m–A* (Fig. 2a) and for an increase in the aging rate *d*(*m*) (Fig. 2b).

The aging rate is the same for one country in history up to the middle of the 20th century. However, for the turn of the 20th–21st centuries, there is a sharp decrease in the curves of the aging rate for the ages 55–75 years (Fig. 3, for example, the increase in the intensity of mortality in 75-year-olds in 20 countries).

For the 12 countries for which data are available since 1900, the decrease in *m–A* for 65-year-olds over the period of 100 years to 2000 averaged at 2.79 times (from 0.0313 ± 0.0070 to 0.0112 ± 0.0019; $P < 0.001$); similarly for the parameter *d*(*m*), it was, on average, 2.81 times (from 0.00279 ± 0.00052 to 0.000990 ± 0.000020; $P < 0.001$). The decrease was the greater, the higher the initial aging rate in 1900: $r = 0.77$ for *m–A* and $r = 0.88$ for *d*(*m*).

The maximum life span as the age of extinction of the standard cohort, reflecting the rate of aging, also increases evenly (for example, for France, from 105–106 years in 1840–1940 to 114 in 2010).

Since 1950 the component *k* in the Gompertz–Makeham formula, reflecting the exponentially increasing mortality rate with age, is taken as the main characteristic of the aging rate (for 12 countries from 0.177 ± 0.0056 for 1810–1940 up to 0.0833 ± 0.0064 for 1950–2010, $P < 0.001$). For example, a correlation of the component k with the current year in the history of France for 1810–1940 is absent ($r = -0.079$), while since 1950 the correlation has become highly significant ($r = -0.941$).

At the same time, a sharp decrease in the component A (for example, in France, 2.6 times from 1840 to 1940) does not in any way affect the aging rate in earlier historical epochs. At the beginning of the 20th century, component A in many countries becomes negative and the component k, which reflects the rate of aging, decreases the most.

DISCUSSION

A typical Gompertz–Makeham graph is considered to be a graph that gives on a logarithmic scale a straight line from the age of the end of growth and development of the organism (20–25 years) to the age of centenarians (85–90 years), when the curve begins to deviate downward (slowing the aging rate of centenarians). However, real graphs usually show very different forms of the mortality rate curve over history for different countries and at different age periods. This may be the result of the influence of external conditions (as reflected by the constant A) or changes in the aging of the organism (which are believed to reflect the parameters of the exponent R and k). Changes in the rate of aging may also reflect an incremental rate of mortality, $d(m)$, and it is more accurate, since it tracks instantaneous changes in the intensity of mortality, independent of the average value of the constant A.

Using the graph of the increase in the intensity of mortality and the graph of the change in the intensity of mortality minus the constant A the Gompertz–Makeham formula allows us to see that the external diversity of the graphs depends on the differences in external influences on mortality (constants A), while the patterns of changes in the rate of aging persist both in history and for different countries, and their graphs practically coincide.

The regularities of a linear increase in the aging rate (on a logarithmic scale, reflecting the exponential law of the increase in the aging rate with age) from the period from the end of growth and development to the ages of centenarians, and the regularities of a in the aging rate at the ages of centenarians remain. The decrease in the aging rate for the age of centenarians reflects the heterogeneity of the population: heredity can, apparently, affect 25% of the life expectancy and forms the phenomenon of centenarians (Hayflick, 2007; Dato et al., 2017).

The influence of external conditions on the aging rate is quite likely (Finch, 2010; Ribeiro et al., 2017). We also proposed a concept of aging that brings pathological changes in natural aging and age-related diseases closer together (Krut'ko et al., 2018); changes in

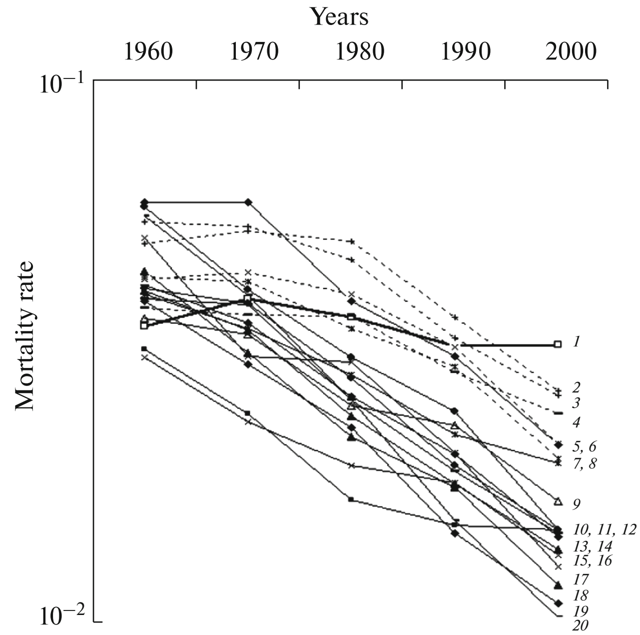

Fig. 3. Change in the historical aging rate of 75-year-olds for different countries, $d(m)$. Designations: *1,* Russia (bold line); *2,* the Czech Republic; *3,* Hungary; *4,* Latvia; *5,* Poland; *6,* Portugal; *7,* Estonia; *8,* England; *9,* Norway; *10,* Finland; *11,* United States; *12,* Italy; *13,* Sweden; *14,* Spain; *15,* Australia; *16,* Canada; *17,* New Zealand; *18,* Switzerland; *19,* France; *20,* Japan. Dashed lines denote post-Soviet countries.

overall vitality during pathological processes are equivalent to the effect on biological aging. In this case, the prevention of age-related diseases and a high level of medical and social assistance will affect the apparent rate of aging, although at older ages of centenarians pronounced changes in physiological parameters during natural aging neutralize this effect and lead to the inversion of reduced mortality at the age of centenarians (Dontsov, 2019b).

The pronounced medical, social, and economic improvements in the quality of life, medical examination, disease prevention, and promotion of a healthy lifestyle, which have been observed in history since the mid-20th century, are probably the reasons that have reduced the rate of human aging.

The effect of the decrease in the rate of human aging since the mid-20th century is the most important phenomenon, which is significant both theoretically and practically in the conditions of the constantly increasing proportion of older ages (aging of the population) and an increase in the retirement age. Revealing the nature of this phenomenon is the key to effectively influencing the aging process of a person, which is an old historical dream of mankind.

COMPLIANCE WITH ETHICAL STANDARDS

The author declares that he has no conflict of interest. This article does not contain any studies involving animals or human participants performed by the author.

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