The extension of Gompertz law’s validity

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Abstract

The interval 35–85 years is mostly considered as the range of Gompertz law’s validity. Looking at the spectrum of causes of death for the interval 10–30 years we find that its main share is caused by various accidents independent of age. These accidents result in the increase and following plateau of the total mortality curve over the age of 15 years. When the number of deaths from age independent causes (accidents, violence, suicide, accidental falls, etc.) is subtracted from the total number of deaths the linear area begins before the age of 20 years. The linear regression of the logarithm of mortality without accidents was performed for the age interval 20–84 years for six populations (men and women in the US in 1989, in Japan in 1990 and in former Czechoslovakia in 1990). Furthermore, the mortality curves of some causes important at the interval 0–15 years were inspected. Unlike other causes, births do not affect the disposition of children to die of malignant neoplasm of the brain and malignant neoplasm of lymphatic and haemopoietic tissue. © 1997 Elsevier Science Ireland Ltd.

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1. Introduction

The answer to the question: ‘At what age does real aging begin?’ is closely related to the onset of exponential dependence of mortality rates on age (Luder, 1993). Aging is commonly considered to be a continuous accumulation of damage, or deterioration, at the level of cells, tissues, organs or organisms, which ultimately
leads to death (Strehler and Mildvan, 1960; Doubal and Klemera, 1990; Riggs, 1990; Harman, 1991). There are two possible explanations of the fact that the exponential dependence is not before the age of 35.

1. We can suppose that the mechanism which is responsible for the exponential dependence law is switched on at the age of 35 years.
2. The exponential rise exists earlier but it is ‘overlapped’ by other causes independent of age.

The second explanation has been verified in this paper.

The steep decline in the total mortality after the birth demonstrates that the moment of birth represents the greatest sudden change of environment within the limits of conception and death. Within the interval of 0–15 years mortality is so small for the majority of causes that the number of deaths is not statistically significant. The main share consists of congenital anomalies, diseases of the respiratory system and some malignant neoplasms. These diseases cause the main part of the total mortality at the interval of age. The individual curves representing mortality for the majority of causes before the age of 15 are as steep as the curve representing total mortality. The curve for malignant neoplasms represents the exception to this.

Conclusions following from this paper have been limited by the definition of causes listed in the Basic Tabulation List which is part of the International Classification of Diseases 9-th revision (ICD 9) (WHO, 1977). For instance: the item leukaemia in the Basic Tabulation List equals five items (204–208) in the ICD 9.

2. Materials and methods

Human death rate increases exponentially in the interval 30–85 years. It was recognized by Benjamin Gompertz in 1825. The Gompertz relationship may be expressed as:

\[ R_t = R_0 10^{\alpha t} \]  

(1)

where \( R_t \) is the death rate at age \( t \), \( R_0 \) is the theoretical value at birth (approximation for \( t = 0 \)) and \( \alpha \) is the slope of exponential term. The Gompertz equation becomes a linear function when expressed logarithmically:

\[ \log R_t = \alpha \cdot t + \log R_0 \]  

(2)

The WHO database contains the numbers of living people and the number of deaths for all causes (the internet address: www.who.ch/whosis/mort/mort.htm). The Basic Tabulation List from ICD 9 (WHO, 1977) was used in this database for the definition of the causes of death in the period 1979–1990. The 236 causes included in the Basic Tabulation List have been grouped into six basic categories to make the work more synoptic. The first four categories represent the simplest classification of the mortality spectrum. The necessity to exclude the non-biological causes gave rise to a fifth category.
1. Malignant neoplasm (The Basic Tabulation List code B08-B14 or ICD9 code 140–208).
2. Diseases of the circulatory system (The Basic Tabulation List code B25-B30 or ICD9 code 390–459).
3. Diseases of the respiratory system (The Basic Tabulation List code B02, B31, B32 or ICD9 code 010–018, 460–519).
5. All causes except accidents.
6. All causes.

The program Excel was used for computing the logarithm of mortality rates for these six categories. The death rate was computed per 1000 of the population. Looking at the mortality spectrum for the interval 10–30 years we find that the main share is caused by various accidents independent of age. The share of accidents on the total number of deaths for men in the US in 1989 is shown in Fig. 1. The next ten causes in this category there: E47-transport accidents, E48-accidental poisoning, E49-misadventures during medical care, abnormal reactions, late complications, E50-accidental falls, E51-accidents caused by fire and flames, E52-other accidents, including late effects, E53-drugs, medicaments causing adverse effects in therapeutic use, E54-suicide and self-inflicted injury, E55-homicide and injury purposely inflicted by other persons, E54-other violence.

These accidents cause the increase and the following plateau of the total mortality curve over the age of 15 years. The parameters of linear regression are shown in Table 1. The standard error of estimate was used to compare the linearity of the fifth and sixth categories. Three mortality curves (malignant neoplasm, diseases of the circulatory system and diseases of the respiratory system) were inspected visually for 1950, 1955, 1960, 1965, 1970, 1975, 1980, 1985 and 1990 in

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**Fig. 1.** Plot of the share of accidents on total number of deaths in percent versus age in the US in 1989.
### Table 1
The parameters of linear regression for six populations

<table>
<thead>
<tr>
<th>Age interval (years)</th>
<th>$\alpha$</th>
<th>$\log R_0$</th>
<th>$r^2$</th>
<th>S.E. estimate</th>
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</thead>
<tbody>
<tr>
<td><strong>Men in Japan in 1990</strong></td>
<td></td>
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</tr>
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<td>Diseases of the circulatory system</td>
<td>10–84</td>
<td>0.0457</td>
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<td>0.9981</td>
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<td>0.0623</td>
<td>−3.8310</td>
<td>0.9955</td>
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<td>All except accidents</td>
<td>20–84</td>
<td>0.0453</td>
<td>−1.7411</td>
<td>0.9975</td>
</tr>
<tr>
<td>All</td>
<td>20–84</td>
<td>0.0377</td>
<td>−1.2032</td>
<td>0.9803</td>
</tr>
<tr>
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<td></td>
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<td>0.9768</td>
</tr>
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<td>−1.8582</td>
<td>0.9957</td>
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<tr>
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<td>−1.5439</td>
<td>0.9847</td>
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<td>−3.0568</td>
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<td>−0.6578</td>
<td>0.9775</td>
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<td><strong>Women in the US in 1989</strong></td>
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<td>Diseases of the circulatory system</td>
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<tr>
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<td>20–84</td>
<td>0.0361</td>
<td>−1.2101</td>
<td>0.9920</td>
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<td><strong>Men in Czechoslovakia in 1990</strong></td>
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<td>−2.5543</td>
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<td>−1.2990</td>
<td>0.9916</td>
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<tr>
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<td>−0.8317</td>
<td>0.9972</td>
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<tr>
<td><strong>Women in Czechoslovakia in 1990</strong></td>
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<td>−1.7413</td>
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<tr>
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<td>20–95</td>
<td>0.0433</td>
<td>−1.5218</td>
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Japan, in the US and in former Czechoslovakia. The Basic Tabulation List of ICD 7 was used for the period 1950–1965 and the Basic Tabulation List of ICD 8 was used for 1970 and 1975. The WHO database did not enable us to observe mortality over the age of 85 years. I have the data for all causes over the age of 85 in former Czechoslovakia only (The Czech Statistical Office in Prague, 1990a,b). There is no difference between the fifth and sixth categories over the age of 85 because the accidents share is less than 3% of all death causes. The thick line in Figs. 6 and 7 shows the relationship between log $R_x$ and the ages of men and women from the age group over 85 years in former Czechoslovakia in 1990.

3. Results

1. The increase and following plateau in the total mortality curve over the age of 15 years is caused by accidents (the fourth category of causes). The explanation for this phenomenon should be sought for in social development rather than in biological development. When we subtract the number of deaths resulting from accidents from the total number of deaths, we obtain a curve without qualitative alteration of the slope between 20 and 35 years (the curve of the fifth category of diseases). This is shown in Figs. 2–7 for both sexes in three countries (the US in 1989, Japan in 1990 and Czechoslovakia in 1990). It was inspected visually in Japan, in the US and in former Czechoslovakia for both sexes for the years 1950, 1955, 1960, 1965, 1970, 1975, 1980, 1985, and 1990. The curve of the fifth category (all causes except accidents) has a linear order from the age of 20 at least. The
linear regression was computed for intervals which had been selected by visual observation of the graphs for 1990 or 1989 years only. The parameters are shown in Table 1. The standard error of estimate was used to compare the linearity between the fifth and sixth categories. The standard error of estimate was smaller...
for mortality without accidents for all inspected populations except for men in Czechoslovakia in 1990. The fifth curve for all populations is shown in Fig. 8. The smallest values of the standard error of estimate was obtained for the fifth category for men and women in the US. The curve is more linear and its area of linearity is

Fig. 5. Plot of the logarithm of mortality rates for women in Japan versus age for the year 1990.

Fig. 6. Plot of the logarithm of mortality rates for men in Czechoslovakia versus age for the year 1990.
Fig. 7. Plot of the logarithm of mortality rates for women in Czechoslovakia versus age for the year 1990.

wider for the populations of the US and Japan due to the better living conditions (Figs. 2–5). The straight line slopes are higher for the fifth category than for the sixth in all countries for both sexes. These results show that the onset of aging-associated mortality law must be moved down to the age of 20. This is in consensus

Fig. 8. Plot of the logarithm of total mortality rates without accidents for six populations.
with Luder (1993). In that paper Swiss national survival and mortality data from 1978–1983 was analyzed.

2. Figs. 6 and 7 show the relationship between age and log $R_x$ for men and women, respectively in Czechoslovakia in 1990. The value of log $R_x$ appears to increase linearly for both men and women for the ages 85 through to 95. Using linear regression for the age interval 20–95 years the following equations are derived:

$$\log R_{xw} = 0.04579x - 1.73979$$ (3)

$$\log R_{xm} = 0.04253x - 1.29687$$ (4)

The $r^2$ value (where $r$ is the correlation coefficient of the linear regression) for Eq. (3) is 0.9994 for women and for Eq. (4) is 0.9913 for men. Therefore, mortality rates rise exponentially for both men and women and the Gompertz law proved to be valid up to the age of 95 years in Czechoslovakia. Mortality in the US among individuals aged 85 years and older between the years 1956 and 1987 was analyzed in Riggs (1992a). This paper demonstrates that general mortality conforms to the Gompertz law through the age of 95 years for both men and women.

3. The remaining three categories are without any qualitative changes of the slope of the curves between 15 and 40 years (Figs. 2–7). Three mortality curves for all malignant neoplasms, diseases of the circulatory system and diseases of the respiratory system were inspected visually for the years 1950, 1955, 1960, 1965, 1970, 1975, 1980, 1985 and 1990 in Japan, in the US and in former Czechoslovakia and the following qualitative conclusions were obtained:

3.1. Malignant neoplasm

The curves of malignant neoplasms from all populations do not conform to the exponential relationship over the age of 50 and they have the worst regression coefficients when compared with the two other categories of causes. This is consistent with the existence of an inherently susceptible population subset which is depleted faster than the general population (Riggs, 1990a; 1992b; 1993).

Malignant neoplasm of other unspecified sites (ICD9 code: 190–199; where the main portion is represented by malignant neoplasm of the brain) and malignant neoplasm of lymphatic and haemopoietic tissue (ICD 9 code: 200–208) are two main causes of cancer mortality for the age groups 0–15 years. Mortality for the upper defined category of cancers is practically independent of age until 15 years for all inspected populations.

3.2. The circulatory system

The mortality curves of the circulatory system have a linear dependence on age in the logarithmic scale (Riggs, 1990b; 1991). The onset of linear area is usually close to 5 years (Luder, 1993). The linear regression was computed for the interval 10–84 years for this category of diseases (Table 1). The congenital anomalies
represent a dominant cause for the age group 0–10 years. The mortality rates decline from the value −0.1 (birth) to −2 (at the age of 7 years). This is demonstrated in Fig. 9. The decline is caused by depletion of the subset with congenital anomalies. The regression coefficients are higher than 0.986 for all populations from the age interval 10–84 years (Table 1).

3.3. The respiratory system

Less than 9% of all deaths are caused by diseases of the respiratory system. The monotone decline of mortality rates is observed for the mortality caused by diseases of the respiratory system for the age interval 0–10 years in all countries. It is very similar to the situation for curves of diseases of the circulatory system. The mortality rates of diseases of the respiratory system rise exponentially from the age of 40 years. The regression coefficients are higher than 0.99 for five populations in six for the age interval 35–84 years.

4. Discussion

This paper demonstrates that the age-adjusted total mortality excluding the number of deaths resulting from accidents, is Gompertzian at least over the age of 20 for men and women in the US, Japan and in former Czechoslovakia. It is demonstrated in Fig. 8. The log $R$ appears to increase linearly for both men and
women in former Czechoslovakia over the age of 95 years (the regression coefficients are 0.9994 for women and 0.9913 for men). Similar results were obtained for the US in (Riggs, 1992a).

We can presume that the mechanism which is responsible for the Gompertz law is switched on before the age of 15 years. The onset of the Gompertzian area is moved down to the age of 10 years for many individual causes of death (Riggs, 1990b, 1991; Luder, 1993). Consequently, this mechanism probably works before the age of 15.

We can see that mortality rates are independent of age for some causes, from that it follows that the basic mechanism which causes Gompertzian dependence on age does not enforce in this case and that it is ‘overlapped’ by other factors independent of age.

Having excluded accidents, we can now say that this type of curve independent of age is a rare case and can be observed within a relatively small interval compared to the Gompertzian area. For example, this type of dependence can be observed for diseases of the respiratory system between 15 and 35 years for women in Japan in 1990 (Fig. 5) or for carcinomas in the age interval 0–15 for all populations. Mortality rates for carcinomas are independent of age within the interval 0–15 years for all populations. After detailed inspection of the spectrum for carcinomas we can see that most deaths in this age interval are caused by malignant neoplasms of the brain and malignant neoplasms of lymphatic and haemopoietic tissues. Why are the mortality rates for carcinomas independent of age? The answer to this question may help us to understand the reason for the appearance of carcinomas at this age.

Mortality curves for diseases of the respiratory system and for diseases of the circulatory system have another type of dependence within the age interval of 0–15 years. Within this interval the mortality rates of those categories of causes decline dramatically and the same decline is typical for total mortality rates, also. In the case of diseases of the circulatory system, the decline is caused by depletion of the subset with congenital anomalies (Fig. 9). As the curve for diseases of the respiratory system is very similar to the curve for diseases of the circulatory system within the aforementioned interval, we can assume that the same mechanism is affected. In the case of diseases of the respiratory system and of infection diseases, we can also assume that ‘learning’ of the immune system begins at this age and that it can influence mortality curves. We can speculate that no subpopulation susceptible to malignant neoplasms is born. We can infer that the moment of birth is a dramatic change for the individual regarding his respiratory system and his circulatory system but that it doesn’t affect his disposition to malignant neoplasms.

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