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A NON-GOMPERTZIAN PARADIGM FOR MORTALITY KINETICS OF METAZOAN ANIMALS AND FAILURE KINETICS OF MANUFACTURED PRODUCTS

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Abstract

Mortality kinetics of various animal species and failure kinetics of industrial components and materials are in variance with Gompertz's law or law of exponentially increasing force of mortality. A pair of straight lines is in general obtained on a semilogarithmic plot, one for the first part of the cumulative mortality curve, up to its inflection point, the other, for the second part of the survivorship curve, after its inflection point. It is concluded that after a certain species-characteristic age, force of mortality and probability of death cease to increase exponentially with age, with the exception of certain human populations, and remain constant at a high level on the average for the remainder of the life span.

Introduction

Benjamin Gompertz demonstrated in 1825 that the force of mortality in human populations of his era increased exponentially with age (1). In more recent years it has been tacitly assumed that this was true of metazoan animals in general. A survey of recent gerontological literature indicated that practically all mortality data for a great variety of metazoan species have been published in the usual form of free-drawn survivorship curves. There have been only sporadic cases of a Gompertz function fitted on the mortality data from species other than humans. The purpose of this paper is to present a paradigm which describes mortality kinetics more accurately than the Gompertzian model. A mathematical model of mortality kinetics which is consistent with the paradigm has been published recently (2) as well as an earlier brief report (Economos, A.C. and Miquel, J.: Non-Gompertzian mortality kinetics. AGE 1: 76, 1978).

Results

Gompertz's Law

The Gompertz hypothesis states that the ratio of the number of individuals dying over a small age interval, over the number of survivors at the beginning of that interval, increases exponentially with age; this ratio is called "force of mortality" or "age-specific death rate." In Figure 1 mortality data for Drosophila melanogaster (3) are plotted in the customary way so that a "survivorship curve", dashed line, is obtained. The solid line illustrates how the survivorship data can be fitted with a Gompertz function. The Gompertzian function does not represent the survivorship curve over the last quarter of the life span for fruit flies; for other metazoan species, this part can be as large as the terminal 70 per cent. The survivorship curve inflects strongly and becomes clearly "slower" in the latter part of the population life span indicating that the force of mortality is no longer increasing exponentially.

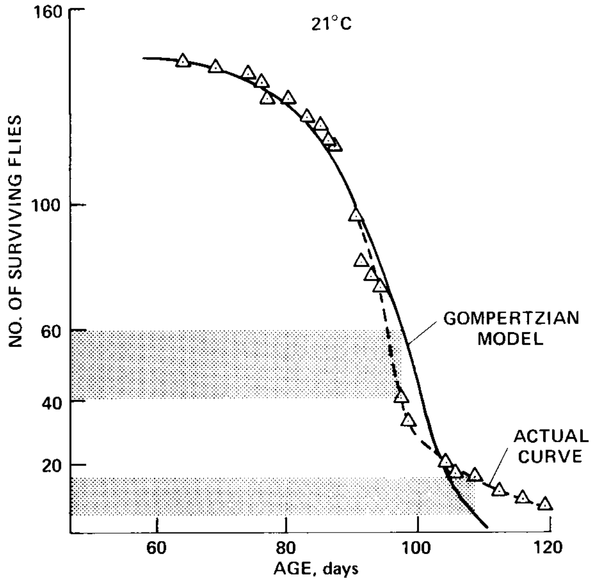

Fig. 1. A typical survivorship curve and its fit using the Gompertz function. Note the large deviation of the model from the actual curve, e.g., hatched areas, starting at about 95 days of age, i.e., at the inflection point of the curve. Data represent survivorship with age of *Drosophila melanogaster.*

A Non-Gompertzian Paradigm for Mortality Kinetics

A semilog plot of the number of survivors in Figure 1 as a function of age gives a curve consisting of a convex part over about 75 percent of the life span and ending in an apparently straight line segment, the survivors line, over the last 25 percent of the life span. On plotting the corresponding cumulative mortality curve on the same plot a complementary picture is obtained: a long straight line segment, the non-survivors line, followed by a shorter convex part. The age which marks the termination of the non-survivors line and the beginning of the survivors line corresponds to the inflection point that is generally present in the plot of survivors against age of most metazoan species under optimal environmental conditions. Some examples are shown: for four invertebrates, nematodes (4), *Campanularia flexuosa* (5), rotifer (6), and shrimp (7), in Figure 2; and for three male rodents, guinea pigs (8), rats (9), and mice (10), in Figure 3; in addition, the paradigm has been shown to hold for the three insect species to which it has been applied. The same paradigm is also useful in describing the

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failure kinetics of industrial products; fatigue life of steel (11), 26 industrial relays (12) with a maximum life span of 95 million operations and motor heat insulators (12) with a maximum life span of 1000 hours when tested at 200° C.

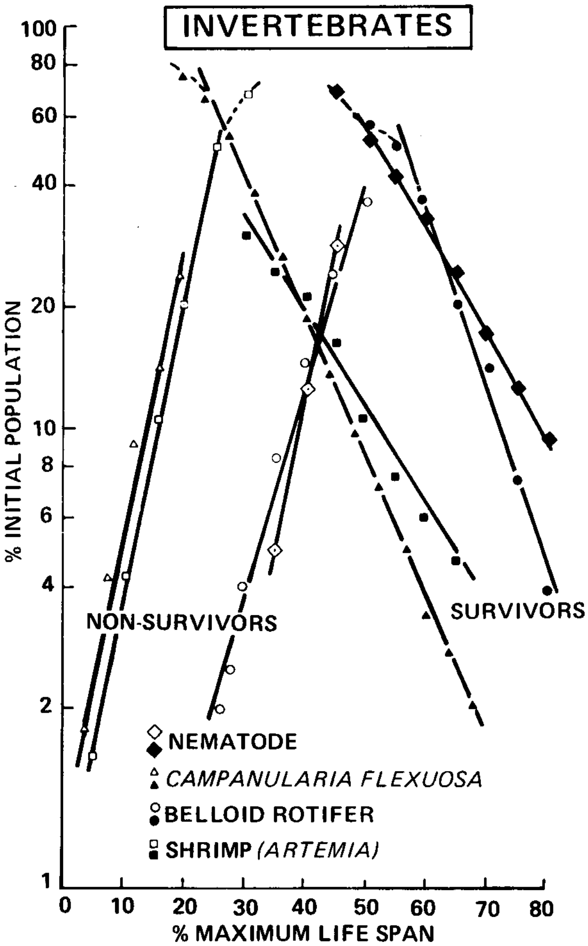

Fig. 2. Non-Gompertzian mortality kinetics of four invertebrate species: nematodes, *Campanularia flexuosa*, rotifers and shrimp, plotted according to the introduced paradigm.

Mortality kinetics of heavily predated natural populations generally lack a non-survivors line whereas humans and animal populations in suboptimal environments lack a survivors line. In the latter case Gompertz's law is valid over the entire life span; in the former force of mortality is constant throughout the life span.

Discussion

Gompertz was an actuary and his interest in mortality kinetics was confined to the inhabitants of England at the beginning of the nineteenth century. Data on other metazoan species were not available at that time. The data available today show that Gompertz's law is an approximation. For most species, the force of mortality and probability of death cease to increase exponentially with age, after a certain species-characteristic age, and remain on the average at a constant high level for the remainder of the life span.

The non-Gompertzian paradigm presented in this report describes mortality kinetics accurately, is simple to employ and should facilitate study of the effects of environmental factors, nutrients, drugs, etc., on the life span.

Acknowledgement

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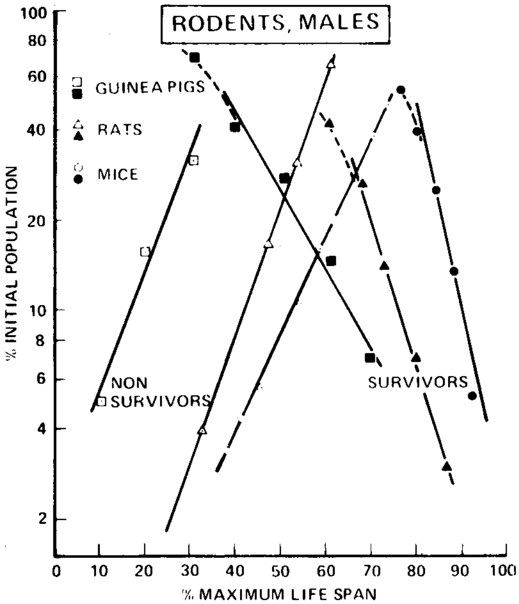

Fig. 3. Non-Gompertzian mortality kinetics of three rodent species, guinea pigs, rats and mice.

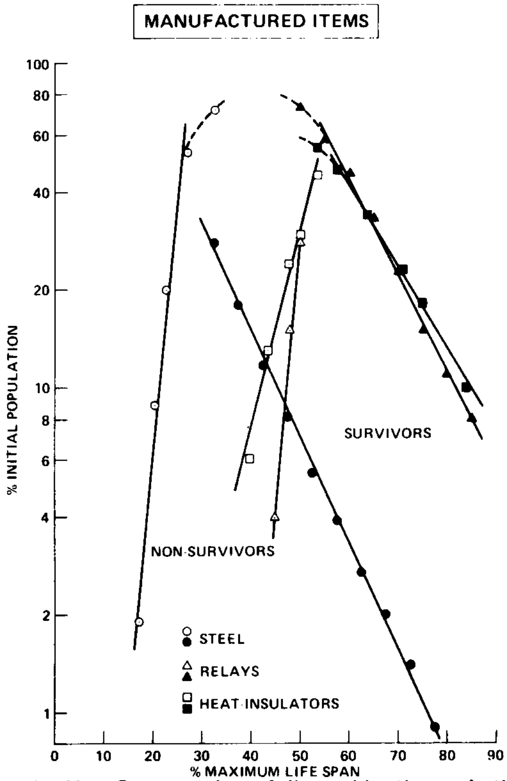

Fig. 4. Non-Gompertzian failure kinetics of three industrial materials: steel, industrial relays and motor heat insulators.

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