How Long Can We Live? A Review Essay*

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The quest for a longer, healthier life is the subject of a recent book by Jay Olshansky and Bruce Carnes. Written for both popular and professional devotees of the subject, the book is lucid and eminently readable. Personal anecdotes illustrate key points, adding warmth and charm to the discussion and spicing up topics that might otherwise deter all but the most serious reader. I enjoyed reading this book and learned a great deal from it. It does a great service by debunking the plethora of claims about potions, treatments, lifestyles, and even biomedical discoveries that promise to halt aging and make us all young again. In spite of its many good qualities, however, I did differ with some of the main points and was surprised by the authors' lopsided portrayal of demographic research on mortality decline and human aging.

During the past decade or longer, the authors and their colleagues have influenced the popular and professional discussion about human aging and mortality trends in various ways. One positive contribution has been educational, as they have explained key technical concepts to nonspecialists in clear terms. In this book as well, they offer helpful discussions of evolutionary theories of aging, related biomedical issues (antioxidants, Darwinian medicine, etc.), and historical trends in mortality and health. Chapter 1 also includes an informative overview of the history of ideas about aging, disease, and death. Over the years another contribution has been the publicity Olshansky and Carnes have brought to this discussion by offering a conservative view about prospects for further increases in human life expectancy. Although some demographers may disagree with aspects of their technical

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arguments or their conclusions, most would probably share the authors' skepticism with regard to commercial products claimed to retard aging and thus significantly extend human longevity.

The core argument

The book covers many topics, but in this review I focus on the issue seemingly most relevant to demographers—namely, prospects for future mortality decline. In this regard, the core argument advanced in this book (and in the technical papers on which it is based) can be summarized roughly as follows. Natural selection has shaped the mortality patterns of humans and other species, resulting in a universal age pattern of "intrinsic" mortality (what remains, theoretically, after all environmental and behavioral influences are removed). This evolutionary legacy of intrinsic mortality imposes strict limits on the amount of mortality reduction that can be achieved merely by manipulating the environment in which humans live or by regulating their personal behaviors. Therefore, further reductions in death rates beyond these "natural" limits can come only through high-tech biomedical interventions that "manufacture survival time." Even if we push beyond these biological limits, however, the rise of life expectancy must slow down in the future because of a force known as "entropy in the life table."

The theoretical and empirical pillars of these arguments are the evolutionary theory of senescence developed by eminent biologists (such as Weismann, Medawar, Williams, and Kirkwood), the authors' own analyses of mortality data for humans and other species, and fundamental mathematical relationships linking death rates and life expectancy (i.e., entropy). In several parts of the book, these concepts are accompanied by analogies drawn from everyday life (race cars, sports records, warranty periods), which give intuitive appeal to the arguments but offer no real scientific support.

Evolutionary theory

In reviewing the evolutionary theory of aging in Chapter 2, the authors have summarized an important body of literature. Later they invoke evolutionary arguments to explain why "sickness, aging, and death make perfect sense for living machines with body designs that were never intended to be tested in the laboratory of extended life" (p. 129). They take the argument a step further, attempting to link theories of the evolution of aging to the diseases that shape modern mortality patterns. "This genetic legacy of biological responses to the hostile environments of our ancestors is directly responsible for the diseases we experience today, and the ages at which they appear" (p. 76). Thus, according to the theory, we are susceptible to late-life disease and mortality because the blind filter of evolution does not care about postreproductive survival. But what does this conclusion about a *pattern* of increasing age-related susceptibility tell us about *levels* of human morbidity and mortality?

Consider cardiovascular disease, the number-one killer in most industrialized nations. This disease is extremely rare among elderly survivors in hunter-gatherer populations, because they do not follow the high-fat diet and sedentary lifestyle common in highly developed countries today (Polunin 1967; Howell 1979). Thus, even if heart disease and stroke become more common with age because of increased susceptibility, their elevated prevalence in modern populations is by no means the inevitable result of our "genetic legacy." Similar arguments can be made for other major diseases, such as cancer. Although I agree with the authors that aging and associated diseases "are not an exclusive by-product of decadent lifestyles" (p. 78), their emphasis on the evolutionary and genetic origins of such conditions goes much too far to the other extreme. Evolution may have shaped the *age pattern* of human mortality, but current conditions and an individual's life history heavily influence its *level*, even in old age.

Laws of mortality

Evolutionary arguments are augmented in Chapter 3 by the authors' own work on the demography of humans and other species. As always, one must applaud any effort to answer fundamental questions about the origins and character of human mortality patterns. Indeed, if one could document a universal mortality pattern across all species (or even within the mammalian class), this would be a finding of the utmost significance. The authors are convinced that such a pattern exists, if we focus exclusively on intrinsic causes of death (Carnes, Olshansky, and Grahn 1996). This is an interesting theory that bears consideration, but it is presented in the book as though it were an established scientific fact. For example, we learn about these ideas in a section of Chapter 3 titled "The law of mortality."

This quaint terminology is often associated with the mortality curve proposed by the nineteenth-century English actuary, Benjamin Gompertz, or with related curves offered by his intellectual successors. By analogy to similar terms from the physical realm (e.g., the "law of gravity"), it suggests that organisms die according to rules that are fixed and unchanging. Indeed, the book claims that the implications of a law of mortality are "staggering," since its mere existence "implies that there are limits to how long humans and other organisms can live, and biological reasons for why such limits exist" (p. 89). Such a statement is utterly naive, however, because the parameters of the Gompertz curve (or of any other so-called law of mortality) can be manipulated to produce any level of life expectancy (or other summary index of mortality). Again, the existence of a general *pattern* says nothing about the specific *level* of mortality.

Entropy in the life table

In addition to discussions of evolutionary theory and a hypothetical law of intrinsic mortality, the book offers a mathematical justification for the contention that the rise in life expectancy must slow down. Even if we succeed in "manufacturing" survival time beyond the limits imposed by human biology, the authors claim that future gains in life expectancy will be smaller and smaller because of "the inescapable reality of entropy in the life table" (p. 88). The book states that "[g]ains in life expectancy are already slowing down and entropy in the life table ensures that future progress will be even slower" (p. 87). The second half of this statement is incorrect. Although entropy was closely associated with the deceleration in the rise of life expectancy during the twentieth century, it has little relevance for future trends.

Briefly, the entropy of any physical system is a measure of its uncertainty. In a life table, high entropy means that deaths are spread over a broad age range. An important result from formal demography is that mortality decline in the presence of high entropy is associated with a very rapid rise in life expectancy, since a high proportion of the deaths averted would have occurred among infants and children. Because mortality risks in adolescence and young adulthood are relatively low, mortality decline at the youngest ages yields a much higher return (in terms of life expectancy at birth) than mortality decline at older ages. In situations of low entropy, deaths are concentrated at older ages and the return from an equivalent proportional mortality reduction is considerably less.

The historic rise in life expectancy was accompanied by a large reduction in the degree of entropy in the life table. A critical point, however, is that it was not entropy *per se*, but rather the *decline* of entropy that produced a slowdown in the rise of life expectancy at birth. As entropy fell precipitously during the twentieth century, the return on reductions in death rates decreased in tandem, and thus the increasing trend in life expectancy decelerated. During recent decades this entropy decline has slowed down, making entropy a less significant factor in life expectancy trends during the late twentieth century than earlier. In the future entropy is expected to stabilize at very low levels,[1] and thus the relationship between mortality decline and gains in life expectancy should stabilize as well. For this reason it is incorrect to claim that entropy in the life table implies a continuing slowdown in the rise of life expectancy (see also Vaupel 1986).

Another important point is that the effect of changing entropy on trends in life expectancy is implicit in any forecast based on extrapolations of age-specific mortality rates, which is the standard method used by demographers. The authors seem to misunderstand the very rudiments of demographic forecasting when they suggest that a "commonly used" technique assumes a linear increase in life expectancy itself (p. 96). This misleading depiction of their colleagues' work opens the door for them to ask indignantly, "Why would scientists who know about entropy in the life table generate such overly optimistic estimates for the future course of life expectancy?" (p. 97).

Indeed, the authors' confusion about the concept of entropy in the life table clouds their entire discussion of mortality forecasts. For example, in discussing an extrapolative forecast that assumes a 2 percent rate of mortality decline across all ages, Olshansky and Carnes assert incorrectly that "entropy in the life table poses a nearly insurmountable obstacle to the 2 percent assumption" (p. 98). As explained above, entropy measures the increase in life expectancy associated with a given decline in death rates. It says nothing about whether an assumed level of mortality decline is achievable or not.

Aside from these conceptual errors, the trend in entropy is only one piece of the trend in life expectancy. The other factor that matters is the rate of mortality decline. Regrettably, the book overlooks a very significant event in the mortality history of highly developed countries during the last decades of the twentieth century: the accelerated pace of mortality decline at older ages, owing to lifestyle changes and medical progress (Kannisto et al. 1994). This more rapid decrease in death rates, combined with a slower decline in entropy, has led to a stable increase in life expectancy at birth, albeit at a slower pace than during the early twentieth century.

The evils of "prolongevity"

The authors use the label "prolongevist" to refer to anyone who is more optimistic about the future of human longevity than they are. Their definition of the term itself is uncontroversial, and it is hard to believe that the authors do not count themselves among those who "believe that aging and death are amenable to modification, and that longevity can be extended through human intervention" (p. 35). However, as used in context it is clearly intended as a derisive term associated in the past with "alchemists" and "hucksters." In modern guise, prolongevists include vitamin vendors, spiritual healers, and overly enthusiastic biomedical researchers, who tempt us with promises of 150- or even 200-year life spans. The authors distinguish three branches of "prolongevity" and note that it takes on extreme and moderate forms. But these distinctions are blurred through most of the discussion, and the book often reads like a holy crusade against the evils of prolongevity in all its manifestations.

One such manifestation, apparently, is modern demographic research. Olshansky and Carnes seem to include almost any demographer who has ever written anything about this topic in the camp of prolongevists. For example, demographers who reject the existence of "biologically imposed upper limits" on the human life span are called "the most zealous advocates of prolongevity" (p. 134). The authors also take aim at demographers who "have developed mathematical models to make forecasts of life expectancy in the future," claiming that such methods "have led some researchers to predict that life expectancy will soon rise to 100 years or higher" (p. 93). Which demographers have made such claims? The book contains no bibliographic references, and the text generally does not cite the names of individuals whose work or ideas are criticized. Therefore, it is worth examining the references that accompany a similar statement in a recent article by the authors in the journal *Science* (Olshansky, Carnes, and Désesquelles 2001).[2]

In short, the authors have created a straw man by misquoting four teams of demographic researchers: Manton, Stallard, and Tolley (1991), Vaupel and Gowan (1986), Wilmoth et al. (2000), and Lee and Carter (1992).[3] *None* of these four articles predicts that life expectancy at birth will exceed 100 years anytime in the future.[4] For example, the most widely cited of these works among specialists in mortality forecasting is undoubtedly the article by Lee and Carter. It anticipates a life expectancy at birth of 86 years in 2065 (for the US) but explicitly rejects higher estimates, noting that "for life expectancy to rise to such a high value as 100 by 2065 would require a radical break in historical trends" (Lee and Carter 1992: 668). Adopting their own tone of indignation, one might ask: Why would scientists who have followed the debate about human life expectancy so closely make such patently false statements about the work of their colleagues?

Mortality limits

In addition to questions about the future of life expectancy, the debate about possible "limits" to the human life span also figures prominently in the book. Here, a difference of perspectives derives partly from divergent definitions of what is meant by a mortality limit. Such a limit usually means either the maximum or the average length of life (in a large human population) that can be achieved by all possible means but never surpassed. These "possible means" include medical breakthroughs as well as other factors, although some medical interventions might be excluded from the definition of a limit if they involve fundamental alterations of the genetic code that defines us as a species. This is the classic definition of a mortality limit, but whether or not such a maximum exists is a different issue (Wilmoth 1997).

The definition of a mortality limit used in this book (and elsewhere by the authors) is quite different. Most notably, the definition is conditional: a limit is "how high life expectancy can climb *without some sort of medical intervention*" (p. 92; emphasis added). To some people, this may seem like a limit that is not really a limit. But even accepting the concept of a movable limit, confusion reigns supreme in the book's discussion of this topic. On the one hand, the authors assert that their conditional limit is 85 years (p. 117, p. 181), but that future advances in biomedical sciences may take life expectancy beyond this level (p. 181). On the other hand, they claim that a biological limit to life expectancy *"has already effectively been surpassed in some populations"* (p. 134; emphasis in original). These statements cannot refer to the same limit, however, because no country has thus far exceeded a life expectancy of 85 years for the total population.

Of course, Olshansky and Carnes can propose any definition they like, but there is a fundamental problem with their current approach. The authors strongly criticize other demographers while ignoring fundamental differences in definitions. They claim that demographic forecasts do not reflect "biological constraints that limit the duration of life" (p. 99), but in making such statements they assume an absence of medical innovation. Forecasts by other demographers assume implicitly that medical progress will continue into the future. Perhaps both approaches have merit, but this difference should be acknowledged explicitly as a source of disagreement. In reality, the difference of opinion between the authors and other demographers about likely future trends in life expectancy is much smaller than they suggest in their book.

Policy implications

Overall, this is a thought-provoking book, even if one does not accept its main arguments. Furthermore, its policy implications are nontrivial: If our goal is to extend human longevity further, then biomedical research should concentrate on re-engineering human bodies and rewriting the human genome (see also Olshansky, Carnes, and Butler 2001). An individual's health and well-being may benefit from a good diet, regular exercise, low stress, and other lifestyle factors (Chapter 10). However, because of entropy in the life table and the immovable wall of intrinsic mortality, life expectancy for society as a whole can gain little from further advances in public health, personal behaviors, or improved nutrition. We have already gone beyond the limits imposed by our biological heritage thanks to survival time that has been "manufactured" by medical science. Further gains may come from "[u]nderstanding gene structure, function, and regulation, and learning how to modify and manipulate these genetic attributes in order to preserve and enhance health and extend life" (p. 152).

I was struck by the genetic and biomedical reductionism that dominates the book's depiction of human mortality patterns. The discussion of the role of medicine in mortality reduction emphasizes invasive procedures and heroic interventions (for example, pp. 119–124), and there is no mention of the hypothesis that disease reduction and improved nutrition at younger ages many decades ago may have contributed to improved health and lower mortality at older ages in recent years (Manton, Stallard, and Corder 1997; Barker 1998; Costa 2000). Furthermore, because of their belief in genetically determined intrinsic mortality, the authors have excluded public health and behavioral modification from future mortality reductions: "Short of medical interventions that manufacture survival time, there is very little you can do as an individual to extend the latent potential for longevity that was present at your conception" (p. 236).

On the one hand, I agree with the authors that much (perhaps most) of the gain in life expectancy since around 1970 in developed countries is attributable to modern medical care. On the other hand, it is important to recall that some of the most effective medical interventions occur before the onset of life-threatening disease—for example, the preventive control of hypertension and high cholesterol via prescription drugs and medically informed dietary modification. From my perspective, these are extensions of a long-term process of changing human habits. In such cases nothing has been "manufactured" by "medical miraclemakers"—we are merely learning how to care better for our bodies and thus to avoid (or postpone) disease. These sorts of changes will no doubt continue, and they will contribute (along with numerous other factors) to a continued rise in life expectancy.

Conclusion

I think that Olshansky and Carnes underestimate the plasticity of the human organism in response to changing environmental and behavioral conditions. Their bold conclusions about the immutability of intrinsic mortality are not well justified by either the theoretical literature they cite or the data analyses they have performed. Their arguments about entropy in the life table are simply wrong, and their portrayal of the research of other demographers is inexplicably negative. Finally, I find their habit of separating medical interventions from other manipulations when talking about mortality limits to be unjustified and confusing semantic gymnastics. In spite of these criticisms, the book is well written and entertaining, and offers a broad coverage of a complex field. I commend the authors for this achievement.

Notes

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1 Using mortality forecasts for the United States from the Social Security Administration, my calculations show that the decline in life table entropy will reach very low levels (less than 0.5 percent per year) after 2008.

2 Olshansky, Carnes, and Désesquelles (2001) state that "[t]wo methods have been used in recent years to predict that life expectancy at birth will reach 100 years in the 21st century." As in the book, they mention both a risk-factor model (developed by Kenneth Manton and his colleagues) and extrapolative mortality forecasts (a traditional technique in demography). To say that life expectancy will exceed 100 years sometime "in the 21st century" is more plausible than to suggest that it will "soon rise" to this level. Whichever phrasing is used, however, the articles cited by the authors do not in fact make such claims.

3 Even without bibliographic references, the book contains unmistakable references to

these and similar publications by Manton and colleagues (pp. 93–95) and Vaupel and colleagues (pp. 97–98).

4 The study by Manton and colleagues (1991) considers different methods of computing limits to human life expectancy. One of these involves a theoretical model linking mortality with various risk factors. The analysis concludes that "a life expectancy of 95 to 100 years (with a standard deviation of about 10 years) might be achieved by 'optimal' risk-factor interventions" (p. 628). Their last paragraph notes also that "a life expectancy of 100 years has implications for the Social Security and Medicare Trust Funds, private pension systems, health insurance, and the health care system" (p. 631). Thus, although the article describes the risk-factor profile that would be needed to achieve a life expectancy of just under 100 years, and although it considers the social implications of such a development, it does not predict that life expectancy in any population will exceed 100 years at any time in the future. The article by Vaupel and Gowan (1986) explores the impact of different mortality trends on population age structure. The main results consist of population distributions under various scenarios, whose implications for life expectancy are mentioned only briefly at the end of the article. The article contains a section discussing the difference between "insight, prediction and projection," and the authors state that "the purpose of the calculations was neither prediction nor projection, but insight" (p. 432). The article by Wilmoth et al. (2000) documents an increase in the maximum age at death in Sweden from 1861 to 1999, but it does not even contain the words "life expectancy." In its concluding paragraph, it suggests that a continuation of this upward trend seems likely in the future, but it contains no prediction or projection involving specific dates or levels. The mortality forecasts by Lee and Carter (1992) yield a life expectancy at birth of 86 years in 2065 (for the United States) with a confidence band from (approximately) 80 to 90 years.

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