The Average French Baby May Live 95 or 100 Years

J. W. Vaupel[*]

If death rates at each age in France remained at current levels over the lifetimes of babies born in France this year, then more than half the babies would live to celebrate their 80th birthdays. Among baby girls, two-thirds would become octogenarians and half would reach age 85. Death rates have been declining in France (and in most other developed countries as well) for many decades. In particular, death rates among octogenarians and nonagenarians have fallen substantially since 1950. Extrapolating these rates of improvement into the future yields an astonishing result: half of all French babies may survive to celebrate their 95th birthdays and half of French girl babies may become centenarians.

Whether progress in reducing mortality will continue, decelerate, or accelerate is an open question. Biomedical research may fail to continue to produce the advances needed to save lives. Social and economic conditions may become unfavorable. Environmental conditions may substantially deteriorate. Nuclear war may kill millions or even billions. New diseases, like AIDS, may decimate populations.

On the other hand, biological, medical and gerontological breakthroughs could lead to considerable extensions of the human life span. The life sciences may be poised at roughly the point the physical sciences were a century ago: biological innovations comparable to electricity, automobiles, telephones, television, rockets, and computers may be forthcoming. Fundamental advances could occur over the coming decades in genetic engineering, in the prevention and treatment of such diseases as arteriosclerosis, cancer, diabetes, and dementia, and perhaps even in understanding and controlling human aging itself. It will be 80 years before a newborn turns 80; a great many unanticipated advances may be made over those eight decades.

The future is not just uncertain, it is surprisingly uncertain. As Ascher (1978), Keyfitz (1981), Stoto (1983) and others reviewed by Ahlburg and Land (1992) have demonstrated, the actual course of demographic events often leads to outcomes beyond the most extreme projections. Consequently, forecasts ought to include wide bands of uncertainty that spread outward at an expanding pace into the more and more distant future. On the one hand, the year 2096 is less than a life span away: some children alive today will almost certainly still be alive then.

[*] Odense University Medical School, Odense, Denmark

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On the other hand, the most radical changes can occur in a lifetime; the year 2096 may be as astonishingly different from 1996 as 1996 is from 1896.

Under the mortality regime that prevailed in France in 1896, only three newborn boys and four newborn girls in 100 would live to age 85. Under the mortality regime that prevails in France today, a quarter of newborn boys and half of newborn girls will live to 85. Some of this change reflects improvements in infant, child, and young adult mortality, but a substantial proportion reflects progress in reducing mortality at older ages. At 1896 death rates, only one girl in two could expect to live to age 60. Of the women who reached age 60, less than one in eight would reach age 85. At current death rates, over 95 % of baby girls can expect to reach age 60, so survival to 60 has doubled, from 50 % to 95 %. At current death rates, half of the women who reach age 60 can expect to survive to age 85, so survival from 60 to 85 has quadrupled, from less than one in eight to one in two. This radical improvement in life chances, especially at older ages, could hardly have been foreseen in 1896.

If something goes badly wrong – environmental collapse, nuclear devastation, etc. – then the cohort born in 1996 may lead short, miserable lives. If health, economic, and social progress accelerate, then there is some chance that most of the members of this cohort will survive into the 22nd century. My best guess among this very wide range of possibilities is that half of the babies born in France this year will reach age 95 and that most of the girls will reach age 100. This is speculation, as are all predictions, and perhaps more tantalizing than informative. What definitely is informative, however, and what definitely constitutes an important intellectual advance is the new light that has been cast on longevity and survival by new data sets. My speculation about the life spans of French babies is informed speculation based on paradigm-shattering findings from these new data sets.

In particular, until recently little was known about the plasticity of oldest-old mortality. Demographers conjectured that mortality at advanced ages was intractable. Specifically, they assumed that rates of mortality improvement at older ages were slow, decelerated with increasing age, and decelerated with increasing life expectancy. These assumptions were justified by appeal to three related notions:

1) Deaths at older ages are essentially due to old age, and nothing can be done about old age;
2) The typical human organism is not constructed to survive much past age 80 or 90;
3) Causes of death at younger ages are largely extrinsic but causes of death at older ages are mostly instrinsic, and it is very difficult to reduce intrinsic causes of death.

These beliefs led most demographers to predict that human life expectancy would not increase very much in the future.

Evidence is now available about mortality after age 80 in a variety of developed countries for several decades. Biological evidence is also now available that permits deeper understanding of the genetic and environmental factors affecting longevity and mortality in a variety of species. This new evidence is inconsistent with previously accepted views. In particular, mortality improvements at advanced ages have been large and have accelerated as life expectancy has increased. Depending on the country examined and the analytical perspective adopted, mortality improvements may not decline with age. In addition, the new evidence casts doubt on the notions that nothing can be done about old age, that organisms are not constructed to survive past some age, and that it is useful to distinguish between extrinsic and intrinsic causes of death. It is this new evidence and its implications that are the focus of this essay.

Prior to 1990, only a few, scattered pieces of research shed light on mortality at the oldest-old ages above 80. Key contributions included Vincent (1951), Depoid (1973), Thatcher (1987), and Kannisto (1988). In particular, very little was known about the plasticity of oldest-old mortality. Lacking empirical studies of large numbers of life tables for the oldest ages over time and place, demographers surmised that mortality at advanced ages was intractable. Specifically, they assumed that rates of mortality improvement at older ages were slow, decelerated with increasing age, and decelerated with increasing life expectancy. In estimating model life tables at low levels of mortality, Coale and Guo (1989) relied on all three of these assumptions. So did Bourgeois-Pichat (1952, 1978) and Demeny (1984) in making forecasts about upper limits to human life expectancy, forecasts that already have been exceeded in some countries. As Keilman (1995) has documented, for several decades nearly all the forecasts produced by national statistical offices have erroneously assumed that rates of mortality improvement at older ages would be slow and would decline with time.

Because of painstaking work by a group of diligent demographers, death counts and population counts by single year of age up to the highest ages and by single year of time back four decades or more are now available in the Odense Archive of Population Data on Aging for most developed countries, including France. These data were largely compiled and organized by Väinö Kannisto, supplemented by data for England and Wales provided by A. Roger Thatcher, data for Sweden from Hans Lundström, data for Norway from Jens Borgan, and data for Denmark from Kirill Andreev and Axel Skytthe. Conjecture can now be replaced by demographic analysis. A stream of research based on the new data is beginning to appear, including Kannisto (1994, 1996), Kannisto et al. (1994), Vaupel and Lundström (1994), Manton and Vaupel (1995), Vaupel and Jeune (1995a), and Thatcher et al. (1997).

This essay adumbrates the major findings reported in this earlier research and adds further findings contained in new tables and figures. The basic thrust of the research is that mortality at older ages is plastic and has been substantially reduced in recent decades. Rates of improvement have tended to accelerate with time.

Table 1. Central death rates for aggregate of Denmark, Finland, Norway, and Sweden, for males and females, for sexagenarians, septuagenarians, octogenarians, nonagenarians, and centenarians in 1880–99, 1930–49, and 1989–93, as well as ratio of values in 1880–99 to values in 1989–93, ratio of values in 1930–49 to values in 1989–93, and annual average rates of mortality improvement between 1880–99 and 1989–93 and between 1930–49 and 1989–93.[1]

	Age	Central death rates (%)			Difference between rate in this period and rate in 1989–93		Ratio of rate in this period to rate in 1989–93		Annual average rate of mortality improvement from this period until 1989–93	
Sex	category	1880–99	1930–49	1989–93	1880–99	1930–49	1880–99	1930–49	1880–99	1930–49
Males	60–69	3.7	3.0	2.2	1.5	0.8	1.68	1.38	0.51	0.62
	70–79	8.5	7.2	5.5	3.0	1.7	1.54	1.30	0.43	0.51
	80–89	19.6	17.3	13.3	6.3	4.0	1.47	1.30	0.38	0.51
	90–99	38.4	36.5	28.7	9.7	7.8	1.34	1.27	0.29	0.47
	100+	95.9	76.9	52.9	43.0	24.0	1.81	1.46	0.59	0.73
Females	60–69	3.1	2.4	1.1	2.0	1.3	2.72	2.12	0.98	1.44
	70–79	7.5	6.4	3.1	4.4	3.3	2.45	2.11	0.88	1.44
	80–89	17.2	16.1	9.1	8.1	7.0	1.89	1.77	0.62	1.10
	90–99	34.5	33.9	23.4	11.1	10.5	1.47	1.45	0.38	0.71
	100+	66.3	70.1	48.5	17.8	21.6	1.37	1.46	0.31	0.73

[1] Statistics in this and other tables and figures in this essay were calculated as follows. The annual age-specific central death rate is given by

$$m(x,y) = D(x,y) / [N(x,y)+N(x,y+1))/2],$$

where $D(x,y)$ represents the number of deaths at age x over the course of year y among males or females, and $N(x,y)$ represents the number of males or females who were x years old on January 1 of year y. The average death rate in the interval from age x through age x^* and year y through year y^* can be calculated by

$$\bar{m}(x,x^*,y,y^*) = \left[\sum_{j=y}^{y^*} \sum_{i=x}^{x^*} w(i)\, m(i,j) \right] / \left[\sum_{j=y}^{y^*} \sum_{i=x}^{x^*} w(i) \right].$$

The weights w are used to standardize the sex and age composition of the population so that comparisons can be made over time, across populations, and between sexes. We based the weights on the age composition of the elderly Swedish population, males and females combined, from 1960 through 1993:

$$w(i) = \left[\sum_{y=1960}^{1993} N_m(i,y)+N_f(i,y) \right] / \left[\sum_{x=50}^{111} \sum_{y=1960}^{1993} N_m(x,y)+N_f(x,y) \right],$$

where N_m and N_f denote male and female population counts. Sometimes it was impossible to estimate m for a specific year either because no one was alive at that age and year or because we did not have data for that age and year. In such cases, the m term was dropped from the numerator and the corresponding weight was dropped from the denominator of the expression for $\bar{m}$. All death rates reported in this essay are values for $\bar{m}$. The average annual rate of improvement in mortality from the first period to the second period is given by

$$\varrho = 1-(\bar{m}_2 / \bar{m}_1)^{1/\delta},$$

where $\bar{m}$ is defined in the note to Table 1 and where δ is the interval between the means of the two periods

$$\delta = (y_2+y_2^*)/2 - (y_1+y_1^*)/2,$$

the first period running from y_1 through y_1^* and the second from y_2 through y_2^*.

Findings

The plasticity of oldest-old mortality is clearly revealed in historical perspective. The four major Nordic countries – Denmark, Finland, Norway, and Sweden – have reliable data on population counts and death counts up to the highest ages going back more than a century. In Table 1 central death rates are presented for sexagenarians, septuagenarians, octogenarians, nonagenarians, and centenarians in the aggregate of these four countries combined as if they constituted a single country. The death rates pertain to three time periods: 1880–1899, 1930–1949 and 1989–1993. The dramatic decline in death rates at older ages is apparent from comparison of the death rates in the three periods.

Table 1 provides three measures of mortality decline. The first measure is the absolute difference between death rates in the earlier periods and the most recent periods. Although demographers seldom use this measure, it is a reasonable way of indicating how many deaths were averted and lives saved. Remarkably, the older the age category, the greater was the absolute reduction in death rates. Viewed in this way, mortality becomes increasingly plastic with age. Except for centenarians, greater progress was made for females than for males. The centenarian statistics have to be viewed with caution because there were few centenarians until recently (Vaupel and Jeune 1995b). In the calculations for 1880–1899, the number of male centenarian person-years was less than 100.

It might be objected that the lives of the extremely old are not "saved" for very long. The number of deaths averted at the oldest ages was an order of magnitude greater than the number of deaths averted among the younger elderly, but the remaining life expectancy of the younger elderly is an order of magnitude greater. Furthermore, the quality of life of some very old persons may tend to be, along some dimensions, lower than the quality of life at younger ages. Nonetheless, averting deaths is an important medical and public-health achievement, as well as generally being of inestimable value to the persons whose lives are saved. The fact that the absolute decline in mortality is greatest at the oldest ages is thus of considerable significance.

The second measure presented in Table 1 is the ratio of death rates in the earlier periods relative to the most recent period. The third measure is the annual average rate of mortality improvement between the earlier periods and the recent period. (How these measures were calculated is explained in the note to the table). These two measures are closely related and show the same patterns. Female mortality improved more than male mortality. For females there is a marked decline in the rate of improvement with age, but for males such a decline is much less apparent. For both males and females the rate of mortality improvement accelerated, being substantially greater over the last 50 or 60 years than it was over the last century.

These various findings from Table 1 are consistent with results from an analysis of mortality in Sweden since 1900 (Vaupel and Lundström 1994) and are in

Table 2. Average annual rates of improvement in mortality (in percent) for aggregation of Denmark, Finland, Norway and Sweden, for males and females, for sexagenarians, septuagenarians, octogenarians, and nonagenarians, over successive periods 20 years apart.[1]

Sex	Age category	Time period				
		1880–9 to 1900–9	1900–9 to 1920–9	1920–9 to 1940–9	1940–9 to 1960–9	1960–9 to 1980–9
Males	60–69	0.55	0.36	0.45	0.20	0.60
	70–79	0.48	0.28	0.31	0.21	0.50
	80–89	0.26	0.26	0.22	0.32	0.64
	90–99	–0.02	0.12	0.13	0.36	0.75
Females	60–69	0.76	0.32	0.68	1.71	1.54
	70–79	0.41	0.18	0.40	1.04	2.05
	80–89	0.16	0.09	0.20	0.63	1.74
	90–99	–0.01	0.02	0.02	0.50	1.18

[1] See note to Table 1 for calculation details

general agreement with the patterns since 1950 in 28 developed countries uncovered by Kannisto et al. (1994) and Kannisto (1994, 1996).

Further information about the pattern of mortality decline in the Nordic countries is provided in Table 2. The more rapid rate of improvement for females than males can be seen to be a persistent phenomenon, although the female advantage has tended to widen over time. The rate of improvement accelerated substantially, especially at the older ages and in the most recent periods, and the gain for females was even more striking than the gain for males. For females, the rate of improvement generally declines with age, although in the most recent period the rate of improvement was greater for septuagenarians and octogenarians than for sexagenarians. For males, the rate of improvement declined with age before the 1940s but afterwards the rate of improvement for octogenarians and nonagenarians has been greater than among the younger elderly.

For 13 countries in the Kannisto-Thatcher Oldest-Old Database, reliable population and death counts are available from 1960 to 1992. These countries are Austria, Belgium, Denmark, England (including Wales), Finland, France, the former West Germany, Japan, the Netherlands, Norway, Scotland, Sweden and Switzerland. Figure 1 graphs average annual improvements in mortality for these countries aggregated as if they were a single country. The improvements are measured as average annual changes over successive five-year-periods; the last data point, for instance, pertains to the improvement between 1983–1987 and 1988–1992. A striking feature of the figure is the sharp increase in rates of improvement around 1970: for both males and females and for octogenarians as well as nonagenarians, rates of improvement approximately doubled. Since this transition, however, rates of improvement have hovered up and down around a roughly constant level. Also noteworthy in the figure is the large difference between rates of improvement for female octogenarians compared with the other three groups.

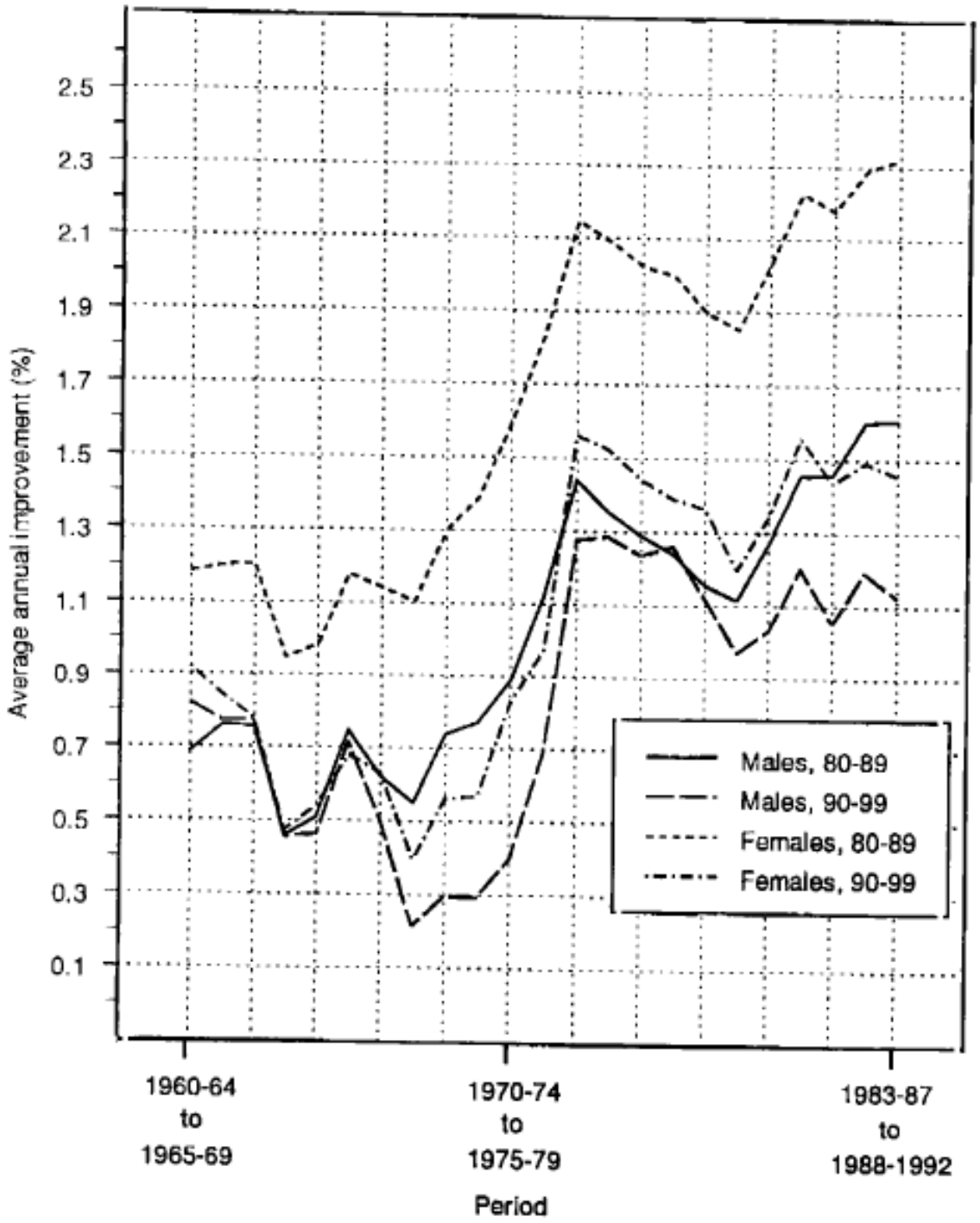

Fig. 1. Average annual improvement in mortality between successive five-year periods, for male and female octogenarians and nonagenarians, in an aggregate of 13 countries

Kannisto et al. (1994) present a similar graph, but for nine countries up to 1989 and for successive ten-year as opposed to five-year periods. Trends in rates of mortality improvement are so important that further analysis is required on a country-by-country basis, using various time periods and using new data for more recent years as they becomes available.

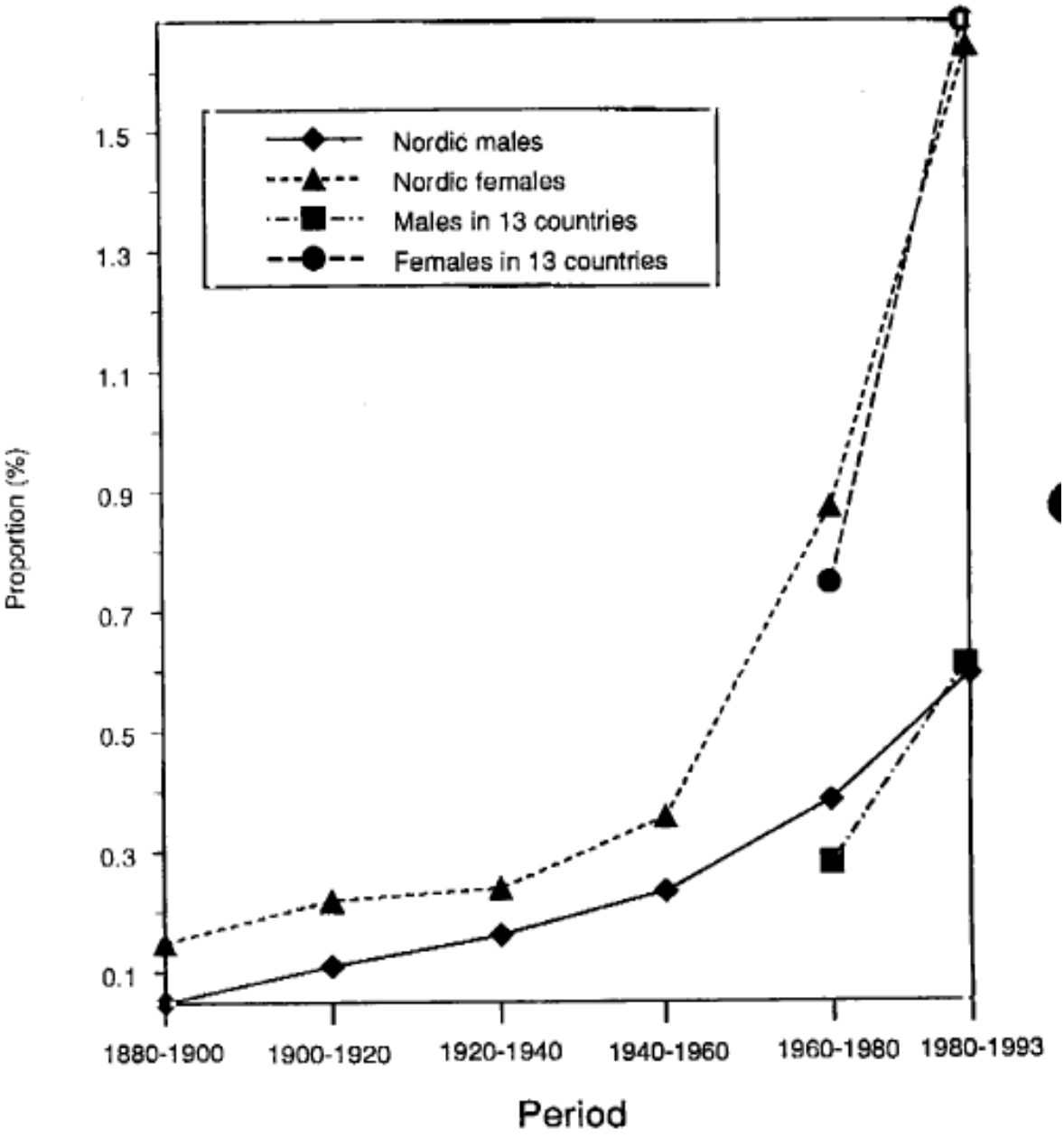

Fig. 2. Life table proportion surviving from 80 to 100

Compared with the chance of surviving from 80 to 100, it is relatively easy to survive to 80. At least for females in developed countries and in some cases for males as well, median and modal life table life spans are above 80 and for females in some developed countries (such as France and Japan) mean life table life spans (i.e., life expectancy) are now around 83. As shown in Figure 2, only a small fraction of those who reach 80 survive to celebrate their 100th birthday. Some of the data are for the four Nordic countries, so that the trend in survival from 80 to 100 can be examined for a period of more than a century. The astonishing increase in an octogenarian's chances of becoming a centenarian, a more than 10-fold multiplication for both males and females, is due to the substantial fall in mortality

between 80 and 100, as documented above. If death rates in some period are R times higher than they were in an earlier period over some age range and if survival over the interval in the more recent period is s, then survival in the earlier period is s raised to the R power. Because of this leverage, moderate changes in death rates can lead to dramatic changes in survival, especially, at ages when survival is low.

Centenarians were so exceedingly rare a couple of hundred years ago that in most countries in most years no one celebrated his or her 100th birthday (Vaupel and Jeune 1995a, b; Wilmoth 1995). The proliferation of centenarians since then

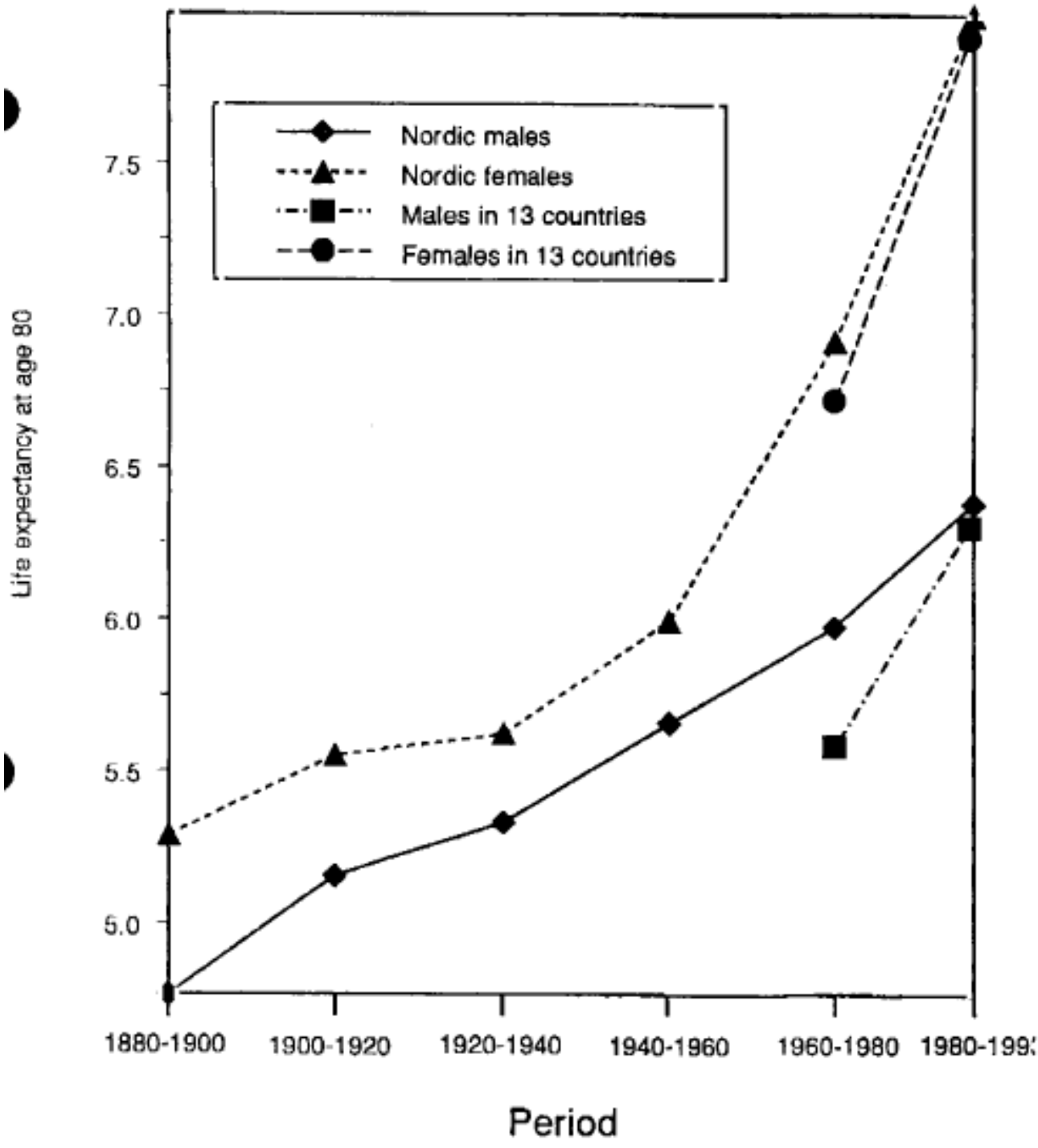

Fig. 3. Life table expectancy at age 80

and especially since the middle of the 20th century is analyzed by Vaupel and Jeune (1995b). As they explain, most of the radical rise in the numbers of centenarians can be attributed to the marked increase in survival from age 80 to 100. The rapid growth of the population of centenarians (by far the most rapidly growing age group in most developed countries, albeit still a small population everywhere) is thus a further reflection of the plasticity of oldest-old mortality.

Figures 3 and 4 depict the rise in remaining life expectancy at ages 80 and 100. Life expectancy is short at age 80 and very short at age 100, but there has been a substantial increase in the time an octogenarian or a centenarian can expect to survive. All things being equal, if remaining life expectancy at some age

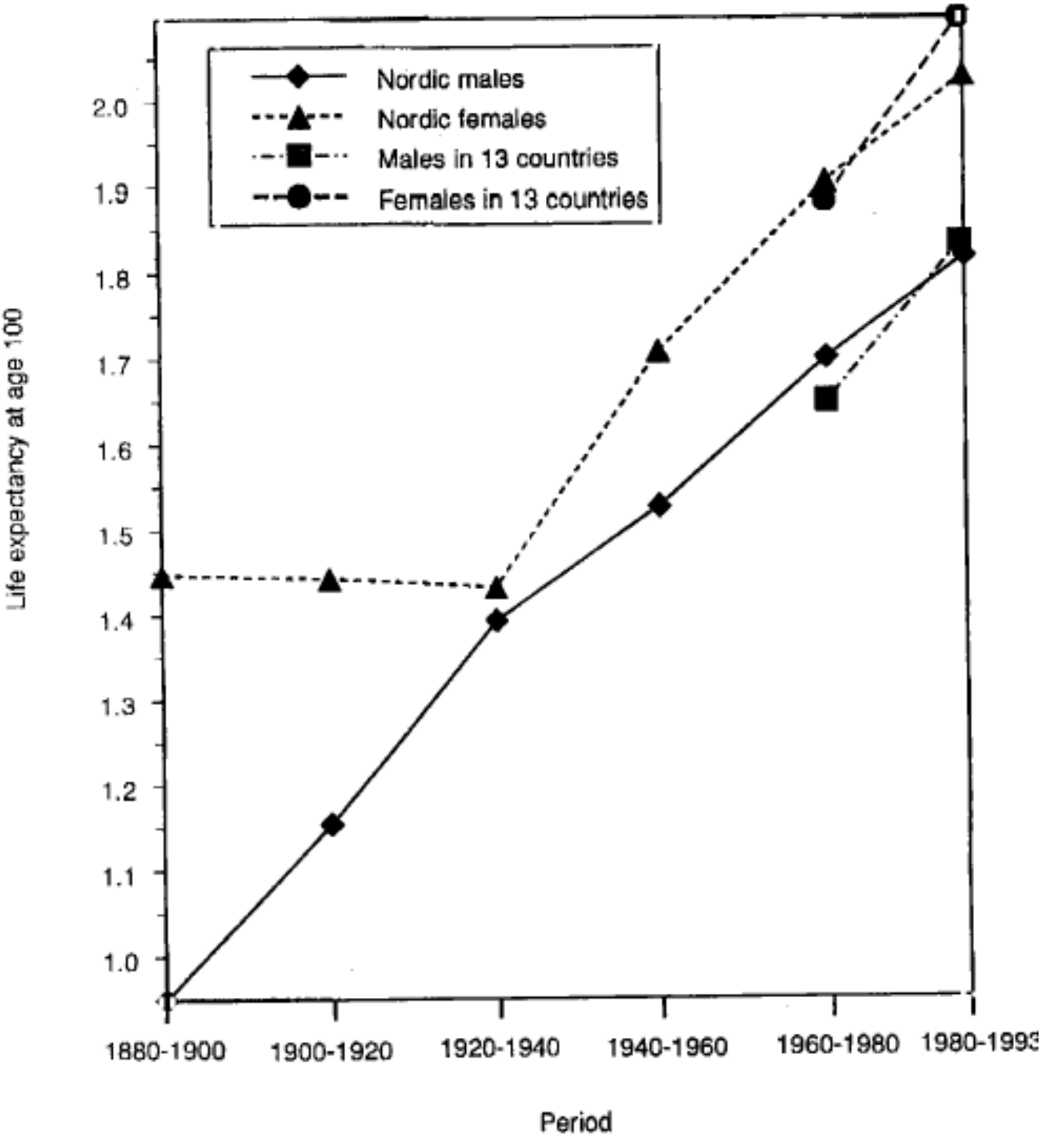

Fig. 4. Life table life expectancy at age 100

increases by some proportion, then population size increases by the same proportion. Hence the increase in life expectancy for 80- and 100 year-old has been a major factor in the growth in the population above ages 80 and 100.

Finally, Figure 5 provides a different perspective on the plasticity of oldest-old mortality by showing the considerable increase in the Nordic countries in the modal life table age at adult death. This measure, which is calculated by finding the age at which the d(x) value in lifetables is maximized, can be considered a measure of the most typical age at death at adult ages or the most common adult life span. In the late 19th century, the modal age hovered around age 75 for males and 76 for females. By the 1940s and 1950s the modal age had risen to about 78

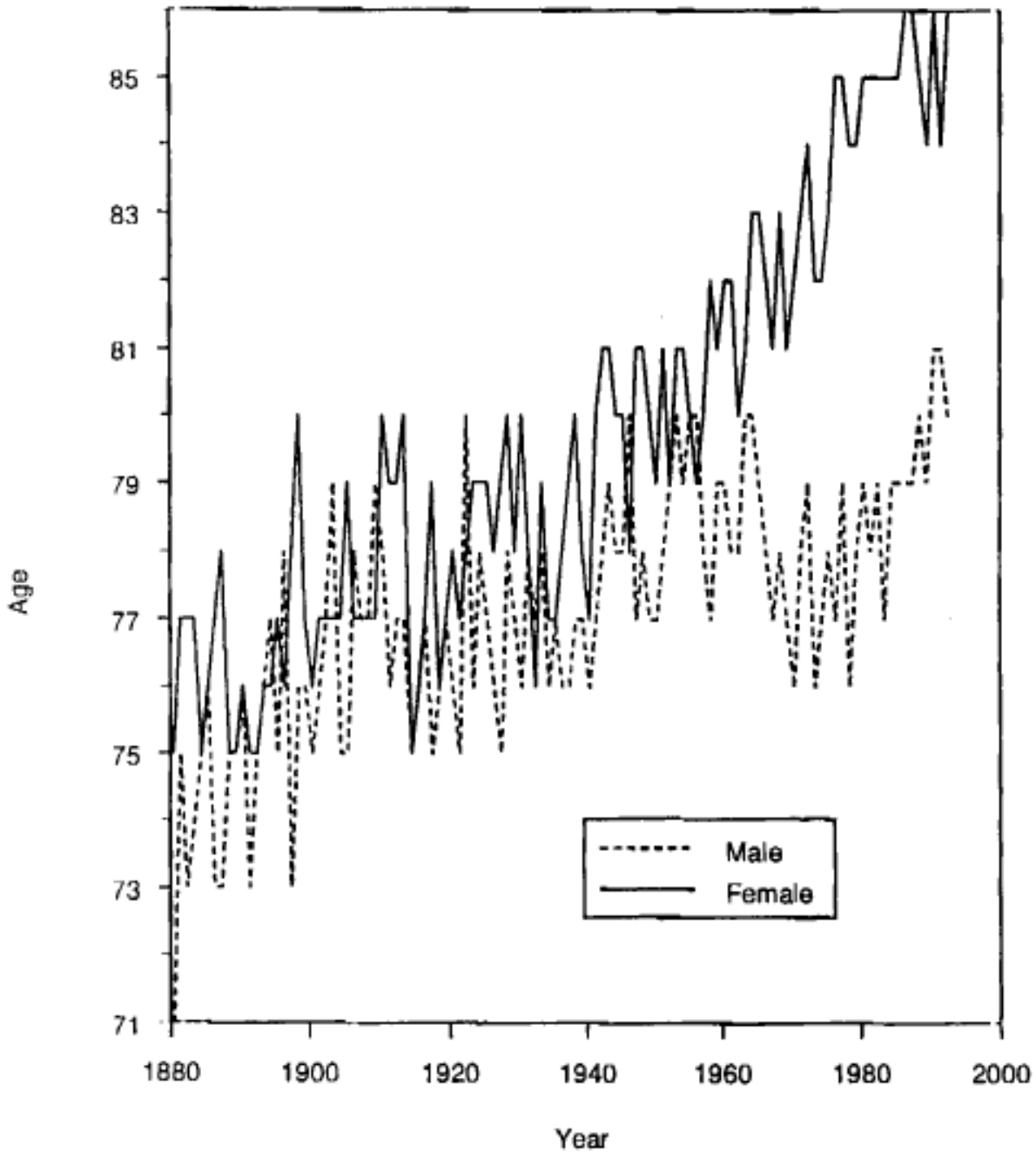

Fig. 5. Life table modal age of death. Aggregate or four Nordic countries, 1880–1993

for males and about 80 for females. Thereafter, the male modal age fell a bit and then rose to a level of 80 or 81 in the 1990s. For females there was a sharp rise in the modal age after 1960, leading to a divergence of female and male values. By the 1990s the female modal age at death hovered between 84 and 86. Over the course of the century from the 1880s and 1890s to the early 1990s, the typical female life span, as calculated from life table values, thus increased by roughly a decade.

Two other measures of the plasticity of oldest-old mortality are worth considering. The first is the age at which remaining life expectancy declines to some level, such as five years. As shown by Vaupel and Lundström (1994) for Swedish females, this age increased by about five years from the 1930s to the 1980s, from 81.5 to 86.7. For males, this increase was about three years, from 80.9 to 83.7. The second measure is the age at which the central death rate reaches some level such as one chance in eight. Vaupel and Lundström's analysis of Swedish data indicates that this age rose from about 81 to about 87 for females and from about 80 to 83 or 84 for males between 1950 and 1990. This age shift in mortality demonstrates that it has been possible to significantly postpone death even among the oldest-old. Information on age shifts in mortality for a variety of countries and at a variety of levels of mortality is presented in Vaupel et al. (1996) and Kannisto (1996).

If it became more and more difficult to make further improvements in mortality as mortality declined, then countries with the lowest levels of mortality might be expected to show the slowest rates of mortality improvement. Furthermore, since female mortality is lower than male mortality, it might be expected that rates of improvement for females would be lower than for males. Data in Kannisto et al. (1994) demonstrate, however, that there is no correlation between the level of oldest-old mortality in developed countries and the rate of improvement. In particular, some countries, such as Japan, that have low levels of mortality also show rapid rates of improvement. Furthermore, in all of the developed countries studied by Kannisto et al. (1994) rates of improvement for females at the oldest-old ages were higher than for males, although levels of mortality for females were lower. This result is consistent with similar findings presented above.

Manton and Vaupel (1995) showed that mortality in the United States after age 80 is lower than in England, France, Sweden, and Japan. The precise extent of the United States advantage is uncertain because of questions about the quality of United States data, but it seems likely that there is an advantage. Manton and Vaupel consider several alternative explanations for this. One possibility is that the United States advantage stems from the quality and extent of health and medical care for the oldest-old in the United States compared with Western Europe or Japan. If so, this would support the hypothesis that oldest-old mortality is amenable to health-care interventions. In any case, there is considerable evidence, briefly reviewed by Manton and Vaupel, that indicates that a variety of interventions can have a major effect in reducing specific causes of death among the very old.

Discussion

Most demographic projections have been and continue to be based on the assumption that mortality is more or less intractable at advanced ages. The results presented above, however, indicate that oldest-old mortality is plastic and has declined substantially over time.

In addition, most projections assume that rates of mortality improvement at older ages decelerate with increasing age. For males after 1960 in the countries analyzed above this was not true: rates of improvement were roughly the same for sexagenarians, septuagenarians, octogenarians, and nonagenarians. For females, however, rates of mortality improvement did tend to decline with age, reaching levels among nonagenarians that were similar to males rates of improvement. If absolute rather than relative mortality improvements are analyzed, then the amount of improvement over time for both male and females is much greater at the oldest ages than among the younger elderly.

Finally, most projections assume that rates of oldest-old mortality improvement will decline to zero over time as mortality declines. In fact, for the countries analyzed above, there was a sharp acceleration of rates of improvement.

The questionable assumptions made about oldest-old mortality have been justified by appeal to three related notions:

1) Deaths at older ages are essentially due to old age, and nothing can be done about old age;
2) The typical human organism is not constructed to survive much past age 80 or 90:
3) Causes of death at younger ages are largely extrinsic but causes of death at older ages are mostly intrinsic, and it is very difficult to reduce intrinsic causes of death.

These three notions are dubious, ill-defined speculations, as explained below.

Deaths, even at the most advanced ages, are not due to old age per se; death is due to the diseases, impairments, and injuries that characterize old age. Such health problems often accumulate and multiply with age, so that it may be difficult to ascribe death to a single cause. If progress is made in preventing, postponing, and treating the ill-health conditions of the elderly, oldest-old death rates will decline. As Manton and Vaupel (1995) note, "health changes once accepted as normal features of aging (e.g. frailty and senility) are now viewed as age-related disorders (e.g., osteopososis and the dementias)."

Mortality at advanced ages can only be ascribed to old age per se if there is some biological clock that determines the maximum life span of an individual. Researchers since Buffon (1835) have hypothesized that such a clock exists and that each individual in every species has a specific maximum life span. Evidence from the exciting new field of experimental demography (Carey et al. 1992; Curtsinger et al. 1992) as well as findings from comparative biology (Finch 1990) and from evolutionary theory (Rose 1991) are inconsistent with this hypothesis.

The notion that individuals are not designed to live longer than some span is also inconsistent with the findings of experimental demography and comparative biology. The maximum life span observed in a cohort of some species depends not only on the species but also on the size of the cohort and on environmental conditions. This is true for humans (Vaupel and Jeune 1995; Wilmoth 1995) as well as for other species (Carey et al. 1992; Finch 1990). Evolutionary theory suggests that species are not "designed" to live some amount of time; a species' design depends on opportunities for reproductive success in a very complicated, competitive environment, with post-reproductive survival being of little or no consequence (Charlesworth 1994). Objects that are designed to last to some specific age frequently survive far beyond that age. The Pioneer space probe was designed to reach Mars; it is still functioning far beyond Pluto. Automobiles may be designed to survive their warranty period, but depending on the model and make and how the vehicle is treated, some cars endure for decades.

The concept that some causes of death are intrinsic and others are extrinsic has seemed appealing to many demographers, from Bourgeois-Pichat (1952) to today. It is, however, a concept that is impossible to put into operation unless the most heroic (and questionable) assumptions are made. Accidental deaths and infectious-diseases deaths might seem to be extrinsic, but mortality from accidents and infections rises exponentially with age at older age. Cancer is usually classified as intrinsic, but almost all cancers are due to environmental insults.

The distinction between intrinsic and extrinsic causes of death is made because it is believed that intrinsic causes are intractable. This contention is questionable. Nearsightedness might be classified as an intrinsic disorder because it is largely genetic in origin; normal vision is readily restored by eyeglasses. The risk of Alzheimer's disease depends on the proteins that an individual is genetically programmed to produce as well as on environmental factors such as blows to the head in childhood. It may turn out to be easier to develop pharmaceuticals that induce the body to produce salubrious proteins than to reduce children's propensity to fall.

In sum, the "theory" underlying many demographers' beliefs about oldest-old mortality is questionable, speculative, imprecise, and inconsistent with available evidence. In the absence of strong theory, demographers should do what they have done since Graunt and Halley: rely on careful empirical studies of the rich lodes of population data. The Kannisto-Thatcher Oldest-Old Database and other databases in the Odense Archive of Population Data on Aging, which are freely available for research, now make such demographic analysis feasible. The results presented above and in other publications based on these data suggest that such demographic analysis will require a radical revision of our understanding of mortality at the older ages when death now usually strikes. In particular, the prospects for longer lives no longer seem as remote as many demographers once thought.

This can be illustrated with a simple calculation that returns us full circle to the start of this essay. At current death rates in France for females, the chance of

surviving to age 60 is some 92 % and the chance of surviving from 60 to 80 is close to 3 in 4. Enduring another score of years is, however, much harder; only one person in 40 makes it. How then can it be plausible that half of newborn French girls may survive to 100? Consider the following scenario. To be conservative, suppose nothing can be done to reduce the 8 % toll of mortality before age 60. Suppose improvements in mortality among 60- and 70-years-old continue to accumulate at about the current rate of 2 % per year. If so, some 85 % of the 1996 cohort of French girls will still be alive at age 80. At current mortality rates, there is an 85 % chance of surviving to age 70, so this progress would simply add a decade of life to the 85 % who live longest.

Now, however, comes the hazardous segment of life from age 80 to 100. If half of the 1996 cohort is to survive to age 100, then almost three in five will have to make it through their octogenarian and nonaagenarian years, compared with one in 40 at current death rates. This is the stage of life during which the most lives will have to be saved. It turns out, however, that the pace of the required improvement is comparable to the pace achieved in France and other developed countries in recent years. What is necessary at these ages is an average rate of mortality reduction of a bit more than 2 % per year. Alternatively what is needed is for the absolute level of mortality at these ages to decline at the same pace as over the past three decades. This is equivalent to requiring that survival from 80 to 100 continues to improve at the same rate as over the last 30 years. In France female survical from age 80 to 100 has increased by a factor of three since the mid 1960s. If it continues to increase by another factor of three every 30 years for the next 90 years or so, then a bit more than three in five of the 1996 female cohort who reach age 80 will endure to age 100.

It would be injudicious to make too much of these simple calculations. Nonetheless, they do suggest that substantial increases in human longevity are not out of the question. Note that the calculations assume that no further mortality reductions are achieved at ages below age 60. Furthermore, the calculations make no assumption about mortality after age 100. The calculations simply assume that future rates of mortality improvement between ages 60 and 80 and between ages 80 and 100 will average about the same pace as in recent years.

Conclusion

Knowledge of the determinants of human longevity is still sparse (Christensen and Vaupel 1996). On the population level, demographic trends can be analyzed, as above. In addition, a number of factors have been identified that are associated with mortality and with cause-specific mortality, such as cigarette smoking, or that appear to be protective, such as red wine. On the individual level, however, these associations are too weak to be reliable predictors of a person's life span. This can be illustrated by a case history. A Danish woman who was born in 1890 and who grew up in a poor family was sent away from home when she was 15 because she had severe tuberculosis that was a potential hazard to the rest of the

family. The infection was treated with an operation. Later she got breast cancer, first in one breast and subsequently in the other, and had both breast removed. The woman herself told this story, which was verified in 1996 shortly after her 105th birthday.

The prospects for deeper understanding of the determinants of longevity may, however, be good. Rapid progress in genetics may add considerably to our understanding of survival. Because the processes of aging in such species as yeast, worms, insects, and rats are similar in some ways to the processes of aging for humans, advances in experimental gerontology may prove to be informative (e.g. Finch 1990; Carey et al. 1992; Curtsinger et al. 1992). Demographic and epidemiological studies of human populations may also play an important role as more reliable and more extensive data are collected and analyzed. Mortality is changing in different regions and countries: life expectancy is declining in Russia and parts of Eastern Europe and increasing in France and most other developed countries. Mortality change in Denmark is following a different pattern than in the other Nordic countries (Härö 1995). In many countries, the changes in mortality rates vary substantially at different ages.

The variety and speed of mortality change provides excellent opportunities for identifying underlying mechanisms and causal factors if appropriate data are gathered, especially data on the specific characteristics of individuals. Particularly in the Nordic countries but also in France, Italy, and elsewhere, the development of large registers of health-related information about individuals – including such special populations as twins, adoptees, and centenarians, as well as the general population – may permit significant development of knowledge about the determinants of the duration of life. Such developments may help inform, as well as being informed by, biomedical research.

If mortality is going to be reduced several fold, continued progress in understanding the determinants of survival and longevity is required. Steady deepening of knowledge, with a cumulative series of research advances, could – and I think probably will – revolutionize how long we live.

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