Reductions in Mortality at Advanced Ages: Several Decades of Evidence from 27 Countries

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HALF OF FEMALE and a third of male deaths in developed countries occur after age 80 (United Nations 1991). If these deaths cannot be further postponed, then health care and biomedical research should be directed elsewhere (Olshansky, Carnes, and Cassel 1990; Lohman, Sankaranarayanan, and Ashby 1992). If progress can be made, growth of the population of the oldest-old—octogenarians, nonagenarians, and centenarians—will quicken (Guralnik, Yanagishita, and Schneider 1988; Ahlburg and Vaupel 1990), with major economic and social consequences including escalation of the cost of health care and retirement programs (Vaupel and Owen 1986; Vaupel and Gowan 1986; Manton 1991; Manton, Stallard, and Tolley 1991).

As reviewed by Manton, Stallard, and Tolley (1991) and by Gavrilov and Gavrilova (1991), many gerontologists and demographers believe that death rates at advanced ages cannot be substantially reduced. Most deaths after age 80 are taken to be natural, senescent deaths due to intrinsic, intractable aging processes. Little, then, can be done about saving lives (i.e., materially postponing death) among the oldest-old. Opinions differ about whether this barrier to progress is due primarily to biological causes (Hayflick 1977; Comfort 1979; Fries 1980; Fries, Green, and Levine 1989; Harman 1991; Carnes and Olshansky 1993; Olshansky and Carnes 1994) or to practical impediments (Olshansky, Carnes, and Cassel 1990), but the canonical view is that in developed countries death rates among the most elderly are approaching limits that can only be relaxed by fundamental and currently unforeseeable breakthroughs in slowing the process of aging itself. This assumption underlies the long-term forecasts of population and mortality several decades hence published by the World Bank (Demeny 1984), the United Nations (1992), and many national statistical offices (e.g., Spencer 1989; Social Security Administration 1993).

Research to test this view has been hampered by lack of accurate age-specific data on mortality at advanced ages for a variety of countries over several decades (Kannisto 1988a; Condran, Himes, and Preston 1991). Age misreporting and other errors in census data lead to substantial errors in population counts at advanced ages (Coale and Kisker 1986, 1990). Data on age at death are generally much better, but even these must be treated with caution (Vincent 1951; Depoid 1973; Kannisto 1988a; Thatcher 1992).

Using a larger body of data than previously available, we find that developed countries have achieved progress in reducing death rates even at the highest ages. Furthermore, the pace of this progress has accelerated over the course of the twentieth century. In most developed countries outside of Eastern Europe, average death rates at ages above 80 have declined at a rate of 1 to 2 percent per year for females and 0.5 to 1.5 percent per year for males since the 1960s.

The database

The data used in this article are from the Kannisto–Thatcher Oldest-Old Database, one of several databases that comprise the Odense Archive of Population Data on Aging, which is maintained at the Odense University Medical School in Denmark.[1] Data for 30 countries (including the United States, Canada, Chile, and Singapore as well as the countries listed in Table 1) on population and death counts after age 80 by single year of age and by single year of time and birth were assembled, tested for quality, and converted into cohort mortality histories by Kannisto, who used an "extinct cohort" method that relies on death counts (Vincent 1951; Depoid 1973; Kannisto 1988a). Data for England and Wales were similarly collected and arranged by Thatcher (1992). Lauritsen and Kirill Andreev created a computerized database for the 27 countries listed, which represent the countries for which reliable data are available for two or more decades. Because international migration is rare among the extreme elderly, the population of persons at some advanced age in some year can be estimated by summing deaths among persons in the appropriate birth cohort at subsequent ages in subsequent years. A count of survivors is needed for birth cohorts that are not yet extinct in the most recent year for which death counts are available. For the Nordic and other Western European countries with population registers, reported survivorship counts are highly accurate. For the other countries the number of surviving elderly in recent years is reliably reported up to age 95 or so and can be reasonably estimated for higher ages.

TABLE 1 Population at advanced ages in 1950, 1980, and 1990: Numbers of persons on 1 January

Country	Abbreviation	Ages 80–99			Ages 100+		
		1950	1980	1990	1950	1980	1990
Denmark	Dk	52,000	142,000	188,000	17	156	325
Finland	Sf	29,000	82,000	138,000	4	42	141
Iceland[a]	Ic	3,000	5,000	6,000	3	6	17
Norway	N	55,000	117,000	156,000	48	154	300
Sweden	S	107,000	254,000	358,000	46	310	579
Austria	A	80,000	198,000	278,000	17	108	232
Belgium[a]	B	120,000	257,000	347,000	—	163	474
England and Wales	Ew	647,000	1,342,000	1,848,000	265	2,140	4,042
France	F	654,000	1,492,000	2,081,000	198	1,886	3,853
Germany (West)[a]	Gw	492,000	1,556,000	2,392,000	63	722	2,528
Italy[a]	I	578,000	1,210,000	1,743,000	104	878	2,047
Japan[a]	J	357,000	1,541,000	2,820,000	126	918	3,126
Netherlands[a,b]	Nl	155,000	310,000	427,000	62	392	818
Switzerland	Ch	52,000	161,000	244,000	10	123	338
Czechoslovakia	Cz	115,000	261,000	354,000	—	—	—
Estonia	Ea	14,000	32,000	40,000	—	—	42
Germany (East)[a]	Ge	228,000	449,000	541,000	—	—	—
Hungary	H	81,000	208,000	260,000	—	—	—
Latvia	La	25,000	57,000	72,000	—	—	—
Poland[a]	Pl	—	491,000	734,000	—	—	—
Australia[a,b]	Au	155,000	243,000	362,000	172	397	507
Ireland	Ir	44,000	65,000	77,000	31	65	87
Luxembourg[a]	Lx	4,000	8,000	11,000	—	—	—
New Zealand[c]	Nz	21,000	52,000	72,000	14	81	196
Portugal[a]	P	86,000	172,000	247,000	—	127	269
Scotland	Sc	66,000	123,000	166,000	—	—	—
Spain[b]	E	280,000	688,000	961,000	—	—	—

NOTES: Countries are grouped according to the quality of the available data, as explained in the text. The symbol — means that population counts were unavailable or of uncertain reliability. See note 1 for the sources of the data.
[a] Instead of 1 January 1950, the population counts refer to 1952 for Italy, 1953 for Luxembourg, 1954 for Germany (East), 1955 for ages 100+ for Japan, 1960 for the Netherlands, and 1961 for Iceland. For Germany (West), the counts refer to ages 80–89 in 1951 and ages 100+ in 1956. For Australia, the counts refer to 1965 for ages 80–97 and 1968 for ages 100+. Information is available for Poland from 1971, and for ages 100+ for Portugal from 1970 and Belgium from 1974.
[b] Instead of 1 January 1990, the population counts refer to 1987 for Spain. The count for ages 100+ refers to 1987 for the Netherlands and 1986 for Australia.
[c] Non-Maoris.

The countries listed in Table 1 are arranged in blocks corresponding to the quality of the available data (Kannisto 1988a, 1994; Thatcher 1992; Condran, Himes, and Preston 1991). The cross-country assessment of relative data quality was done by Kannisto (1994), who checked for age heaping and also subjected the underlying data on deaths to a number of checks for plausibility. Countries that were judged to have highly reliable data provided a set of indicators against which other countries could be compared. As a whole the data-quality indicators for the various countries present a consistent and logical picture with a range of values in which it is possible to discern various degrees of reliability with some assurance when due regard is paid to the degree of aging and the general level of mortality in the country in question.

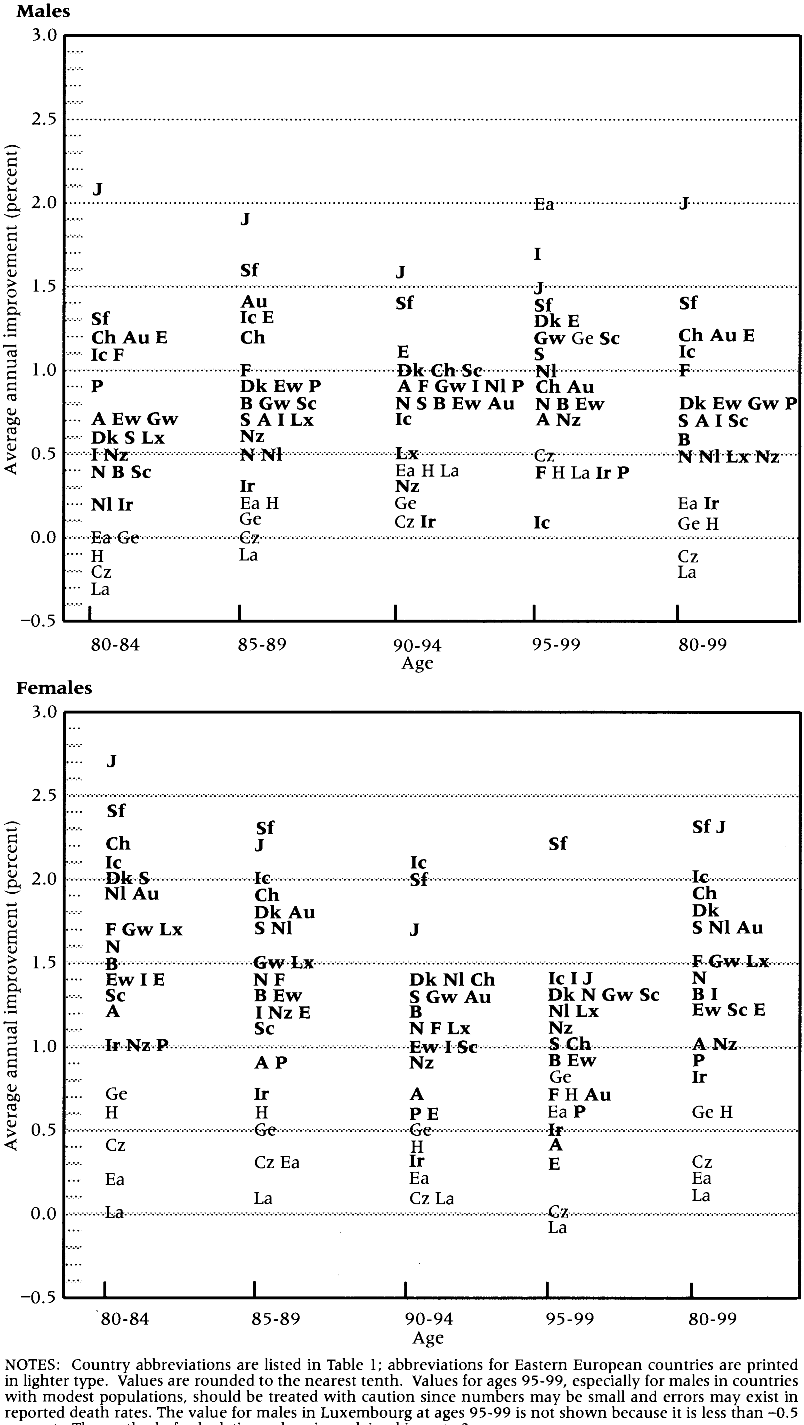
The Nordic countries, shown first, have population registers that give exceptionally reliable data, but the population of these countries is small. Japan and eight Western European countries can be used to supplement the Nordic group to provide an aggregate of countries with a large combined population and highly reliable data. The Eastern European countries share a pattern of mortality change that differs from the other countries. For these six countries as well as for Luxembourg and Scotland, age at death above 100 years is not available. For the remaining five countries, we have not completed an assessment of the reliability of reported ages. Data have also been collected for the United States and Canada, but further work is required for these countries because of the questionable accuracy of information about age.[2]

Fries (1980) predicted that "the number of very old persons will not increase." Combining all populations in Table 1 for which data are available on centenarians, we note that the number of centenarians increased substantially—from less than 9,000 in 1980 to nearly 20,000 in 1990. Indeed, the number of centenarians has roughly doubled every ten years since 1950. Furthermore, the population above age 80 in nearly all countries more than tripled between 1950 and 1990. This proportionate increase is much greater than the proportionate increase in the overall size of the countries' populations. The increase, however, cannot be attributed solely to improvements in mortality in old age. Much of the rapid growth of the oldest-old population was due to progress in reducing death rates at younger ages; increases in the size of birth cohorts in the nineteenth century also contributed (Thatcher 1981).

Rates of mortality improvement

Whether levels of mortality have declined at advanced ages can be determined by considering average annual rates of mortality improvement, that is, percentage reductions in death rates. For almost all countries for which data are available, the average rate of improvement for ages 80–99 combined was positive over the period from the 1960s to the 1980s, for males as well as for females, as shown in Figure 1. In the Eastern European coun-

FIGURE 1 Average annual improvement in old-age mortality for males and females, by age groups, from the 1960s to the 1980s



NOTES: Country abbreviations are listed in Table 1; abbreviations for Eastern European countries are printed in lighter type. Values are rounded to the nearest tenth. Values for ages 95-99, especially for males in countries with modest populations, should be treated with caution since numbers may be small and errors may exist in reported death rates. The value for males in Luxembourg at ages 95-99 is not shown because it is less than −0.5 percent. The method of calculating values is explained in note 3.

tries, which have high rates of mortality and low life expectancy, declines in mortality were less than elsewhere.

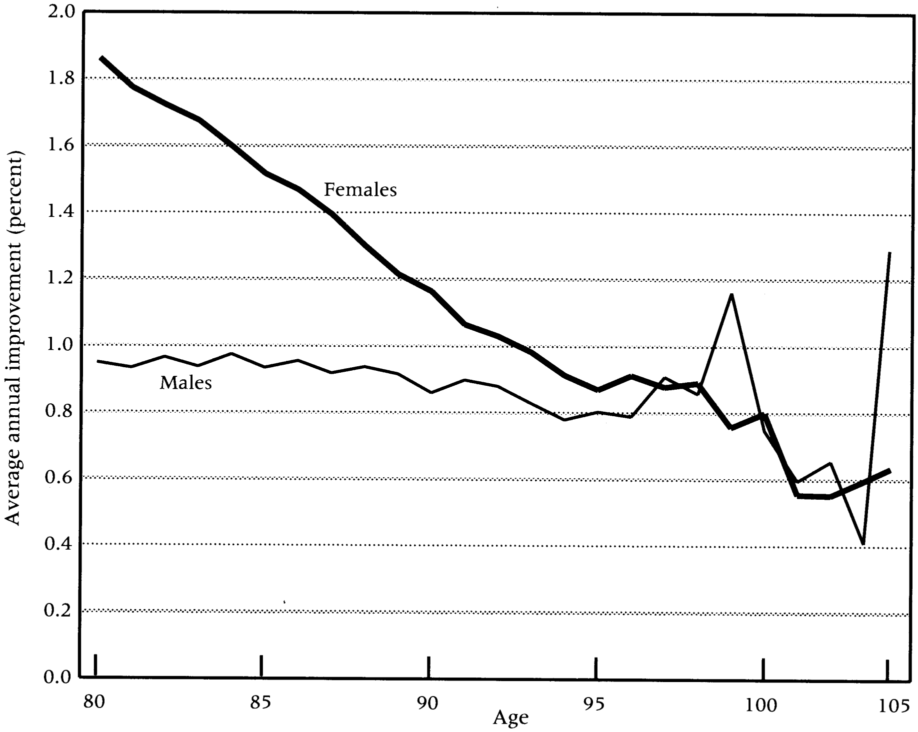
In all of the countries examined, rates of improvement have been greater for females than for males: for ages 80–99 combined, the median annual gain has been 1.3 percent for females and 0.7 percent for males. Among females, progress generally has been greater for octogenarians than for nonagenarians. The more modest improvements for males show no consistent change with age. In Japan and France, two large countries with reliable statistics, gains for males in their early 80s were relatively great whereas gains for males in their late 90s were considerably less. Two other large countries with reliable statistics, Italy and Germany, follow the opposite pattern.

Kannisto (1994) discusses the rate of mortality improvement from 1955–59 to 1985–89 for males and females between ages 60 and 99 in 12 developed countries. For males in Italy, the Netherlands, Sweden, and West Germany mortality gains were nearly as large among 90-year-olds as among 60-year-olds. In Denmark, Norway, Czechoslovakia, East Germany, and Hungary, male death rates *increased* among the younger old but decreased among the older old. Finally, for Finland, France, and Japan, improvements were greater for the younger elderly than for the oldest. For females, the pattern in the 12 countries is less disparate: the pace of mortality improvement in most cases was most rapid among septuagenarians, somewhat slower among sexagenarians and octogenarians, and even slower among nonagenarians.

Rates of improvement for centenarians are not presented in Figure 1 because deaths in individual countries are infrequent and may be less accurately reported at the very oldest ages. For an aggregate of 13 countries with highly reliable data, improvements among centenarians ran at annual rates of about 0.5 percent, as shown in Figure 2. The contrasting pattern of declining female gains with age and of smaller, steadier male gains is striking. The annual rate of improvement for males between the 1960s and 1980s declines only slightly between ages 80 and 98, averaging about 0.9 percent. For females, the rate of improvement falls from a much higher level of close to 1.8 percent at age 80 to converge with the level for males after age 95. Rates of improvement after age 95 have to be treated with caution, since population sizes are modest and errors may exist in some countries' reported death counts. For males as well as females, rates of improvement may have been smaller after age 100 than before this age (Coale and Kisker 1990; Coale and Guo 1989; Coale and Caselli 1990).

For most of the countries outside Eastern Europe, rates of mortality improvement for ages 80–99 have tended to be higher since the 1960s than earlier, as shown in Figure 3. For countries for which data are available, gains between the 1920s and 1930s were close to zero. From the 1930s to

FIGURE 2 Average annual improvement in old-age mortality for males and females, by single year of age, from the 1960s to the 1980s for an aggregation of 13 countries with highly reliable data

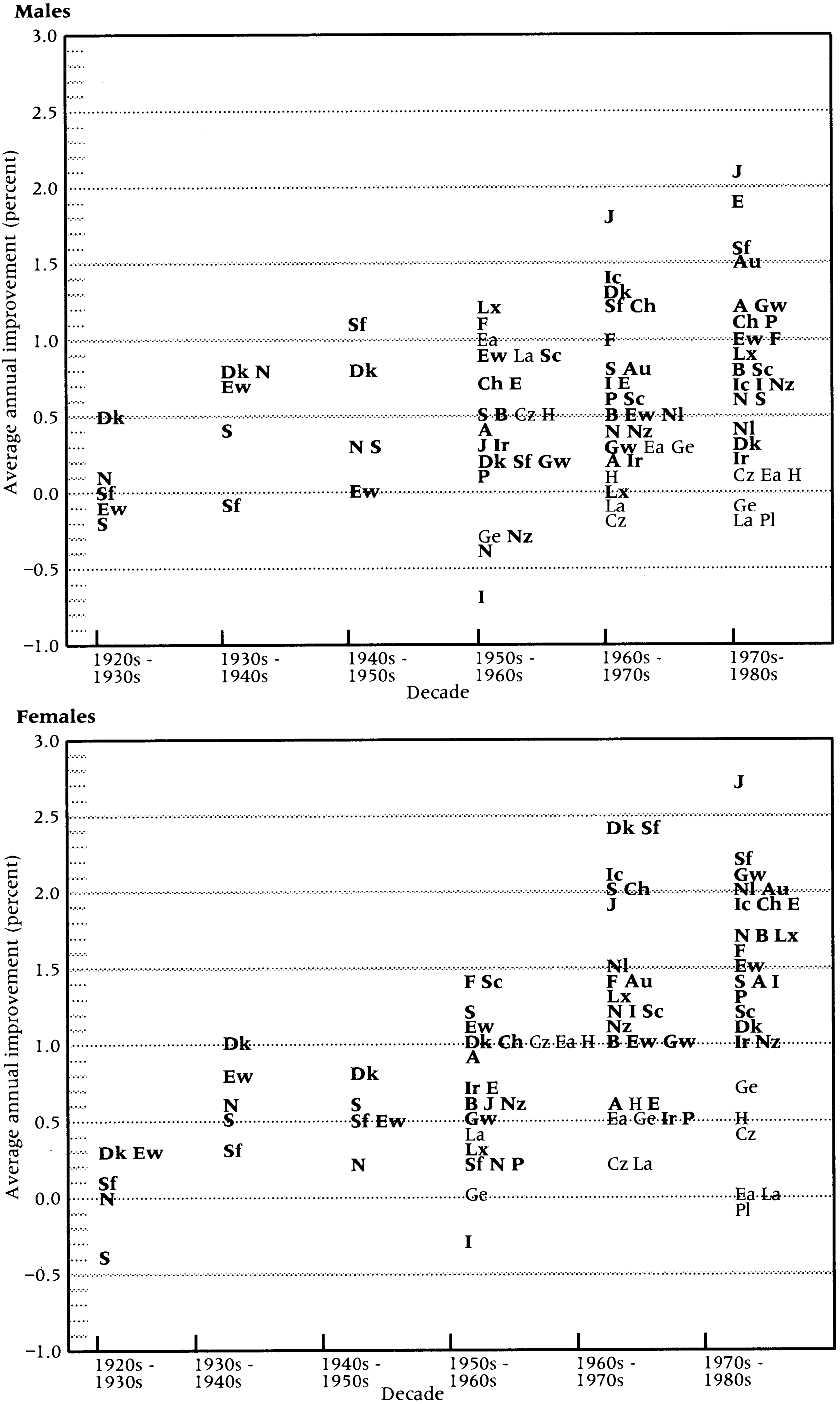


NOTES: The countries are Denmark, Finland, Iceland, Norway, Sweden, Austria, England and Wales, France, Germany (West), Italy, Japan, the Netherlands, and Switzerland. Belgium is not included because data for centenarians are not available for the 1960s. Death and population counts were combined for the countries as if the aggregation were a single country. Values for males and females were then calculated as described in note 3, except that calculations were done by single year of age. The graph is continued to the age such that at least 100 persons were alive at that age in the 1960s. This age is 104 for males and 106 for females.

the 1960s, rates of improvement are scattered around 0.5 percent per year. For the Eastern European countries, improvements in mortality since 1950 have been small and in some instances death rates increased. For most other countries, rates of mortality improvement have accelerated. Increases in the pace of improvement for both males and females in Finland, Ireland, Japan, and West Germany are particularly striking: in all cases the annual rate of mortality reduction between the 1970s and 1980s exceeded the rate between the 1950s and 1960s by a full percentage point or more.

Table 2 provides a summary of the acceleration of the pace of mortality improvement for males and females and for octogenarians and nonagenarians. Data are available for England and Wales and for four Nordic countries (Denmark, Finland, Norway, and Sweden) from the 1920s through

FIGURE 3 Average annual improvement in mortality from decade to decade for males and females, for ages 80-99 combined



NOTES: Country abbreviations are listed in Table 1; abbreviations for Eastern European countries are printed in lighter type. The method used to calculate the average annual improvement in mortality is explained in note 3.

TABLE 2 Average annual improvement (in percent) in mortality, for males and females and for octogenarians and nonagenarians, in England and Wales and in four Nordic countries from the 1920s to the 1980s and in an aggregation of 19 countries from the 1950s to the 1980s

		Males		Females	
Country	Period	Age 80–89	Age 90–99	Age 80–89	Age 90–99
England and Wales	1920s–1940s	0.33	0.01	0.59	0.14
	1940s–1960s	0.43	0.38	0.79	0.59
	1960s–1980s	0.66	0.69	1.21	0.82
Denmark, Finland, Norway, and Sweden	1920s–1940s	0.23	0.21	0.22	0.12
	1940s–1960s	0.32	0.27	0.61	0.42
	1960s–1980s	0.63	0.73	1.74	1.14
19-country aggregation	1950s–1960s	0.48	0.16	0.80	0.24
	1960s–1970s	0.71	0.69	1.19	0.70
	1970s–1980s	1.20	1.00	1.88	1.21

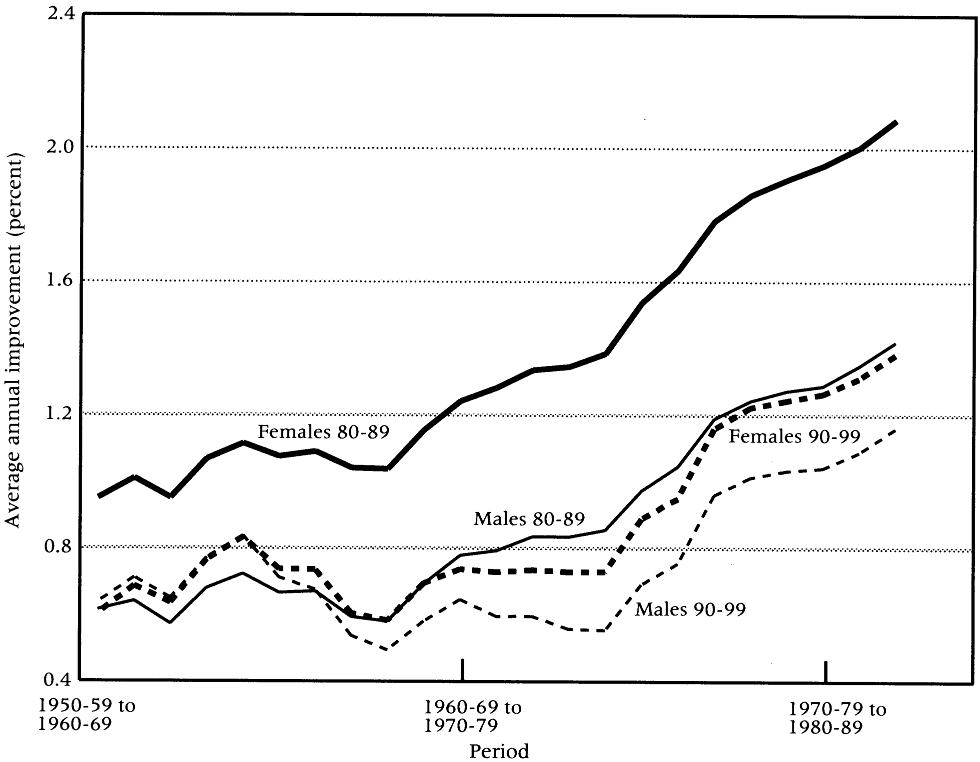
NOTE: The 19 countries are Austria, Belgium, Denmark, England and Wales, Finland, France, Germany (West), Iceland, Ireland, Italy, Japan, Luxembourg, New Zealand (non-Maoris), Norway, Portugal, Scotland, Spain, Sweden, and Switzerland. These are the countries outside Eastern Europe for which data are available from the 1950s through the 1980s. Data are not available for the 1950s for Australia and the Netherlands.

the 1980s. As shown in the table, the rate of mortality improvement increased in these populations over this time. Table 2 also shows the acceleration of mortality improvement in an aggregation of 19 countries outside Eastern Europe for which data are available from the 1950s through the 1980s. Again the pattern is consistent for men and women and for persons in their 80s and 90s: rates of mortality improvement have increased considerably.

For nine countries—Austria, Belgium, England and Wales, West Germany, France, Japan, Scotland, Sweden, and Switzerland—data are available through 1991. Figure 4 shows the acceleration in the pace of mortality reduction for this aggregate. The curves can be interpreted as running averages: in each instance, the rate of improvement is calculated between one ten-year period and the following ten-year period. Starting with the relatively slow rate of improvement between 1958–67 and 1968–77, there has been a marked acceleration through the most recent period, both for males and females and for octogenarians and nonagenarians.

A glimpse at the most recent trends is provided by calculating the annual average rate of mortality improvement between 1982–86 and 1987–91 for this aggregate of nine countries. For males the rate of improvement was 1.7 percent for octogenarians and 1.2 percent for nonagenarians; for females the corresponding rates were 2.5 percent and 1.6 percent. In each instance, these rates exceed—by a quarter to a half percentage point—the respective rates between 1977–81 and 1982–86, showing a continuation of

FIGURE 4 Average annual improvement in mortality between successive ten-year periods, for male and female octogenarians and nonagenarians, in an aggregation of nine countries

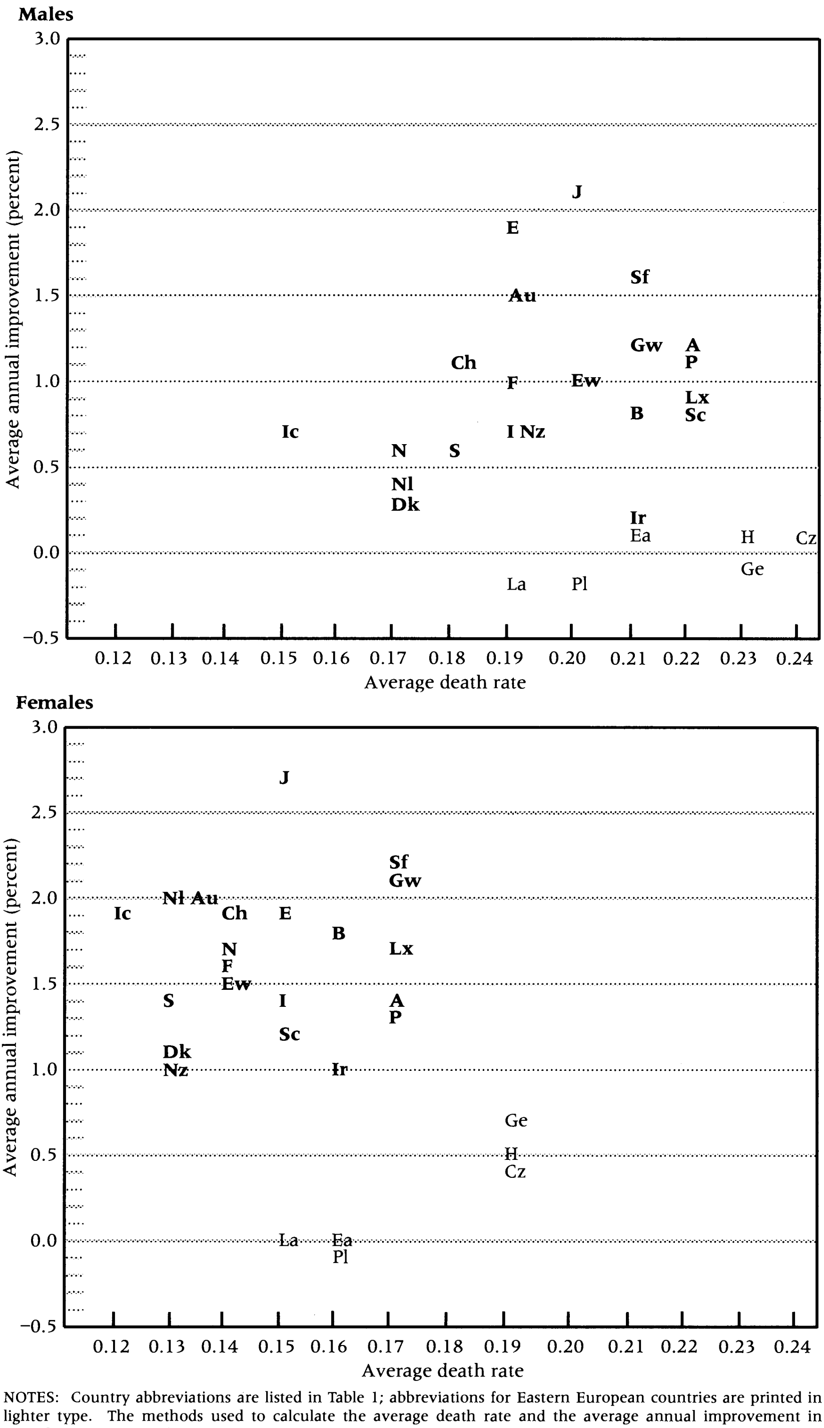


NOTES: The nine countries (Austria, Belgium, England and Wales, France, West Germany, Japan, Scotland, Sweden, and Switzerland) are those for which data were available up through 1991. The curves plot the annual average improvement in mortality between one ten-year period and the next. The last point on the curves gives the rate of improvement between 1972-81 and 1982-91.

the acceleration of mortality improvement up to the most recent point that can be reasonably estimated from the available data.

If mortality among the oldest-old were approaching biological or practical limits, then countries that have the lowest death rates would be closer than other countries to such limits. Rates of mortality improvement, however, are only weakly related to levels of mortality, as shown in Figure 5. Indeed, the Pearson correlation coefficients between the level of mortality at ages 80–99 in the 1970s and the rate of improvement between the 1970s and 1980s are negative: –.10 for males and –.35 for females. The Eastern European countries, which suffer high death rates, showed little or no mortality gains between the 1970s and 1980s. Even if these countries are omitted from the calculations, the correlation coefficients are modest: 0.30 for males and 0.07 for females. Furthermore, values for females in Figure 5 are, for nearly all countries, to the northwest of values for males: death

FIGURE 5 Average death rate in the 1970s compared with average annual improvement in mortality from the 1970s to the 1980s, for males and females, for ages 80-99 combined



NOTES: Country abbreviations are listed in Table 1; abbreviations for Eastern European countries are printed in lighter type. The methods used to calculate the average death rate and the average annual improvement in mortality are explained in note 3.

rates are lower for females than males but mortality improvements are greater.

If uniform mortality limits were being approached in a group of countries, their mortality levels would converge toward the ultimate levels. A decrease in the coefficient of variation—the standard deviation as a percentage of the mean—is an indicator of convergence. For the countries examined, however, the coefficient of variation of the death rate at ages 80–99 increased each decade from the 1950s to the 1980s—from 9 percent in the 1950s to 15 percent in the 1980s for females and from 8 percent to 12 percent for males. If the Eastern European countries are omitted, the coefficient of variation increased from 8 percent to 10 percent for females and hovered around 9 percent for males.

A summary measure of the cumulative improvement in mortality at advanced ages over several decades is the change in the proportion of 80-year-olds who would survive to age 100 at prevailing death rates (Kannisto 1988b). For several reasons England and Wales provide an informative example: mortality patterns there are typical of patterns in other countries, the population is large, and reliable data are available for an extended period (Thatcher 1992). In England and Wales, the proportion surviving increased for males from 0.9 per thousand in the 1930s to 5.2 per thousand in the 1980s, a sixfold increase. For females, the proportion increased from 2.9 per thousand in the 1930s to 18.9 per thousand in the 1980s, also a sixfold increase. Another measure of cumulative progress is the change in death rates at a specific age. In England and Wales, the central death rate for an 85-year-old male fell by a quarter, from 0.24 in the 1930s to 0.17 in the 1980s; and the death rate for an 85-year-old female fell by a more than a third, from 0.19 to 0.11.

Discussion

Other strands of evidence, reviewed by Manton, Stallard, and Tolley (1991), also suggest that mortality among the oldest-old can be further reduced. Some of this evidence pertains to trends in causes of death, some refers to special populations such as Mormon priests, and some is based on the results of mathematical modeling. Several demographic studies have documented decreases in mortality at advanced ages (Depoid 1973; Kannisto 1988a, 1988b, 1994; Thatcher 1981, 1987, 1992). Furthermore, recent research on nonhuman species (Finch 1990; Carey et al. 1992; Curtsinger et al. 1992; Vaupel and Carey 1993) undermines several long-held views: (i) that there is a single, universal process of aging, (ii) that this process results in an exponential increase in mortality with age (Gompertz 1825), (iii) that "like a clock" every individual "is constructed to run a certain time" (*Scientific American* 1991), and (iv) that species have specific lifespan limits.

By drawing on models from reliability engineering (Gavrilov and Gavrilova 1991; Yashin, Vaupel, and Iachine 1993) and on concepts and findings from evolutionary biology (Carnes and Olshansky 1993), gerontologists are beginning to develop a more complex understanding of aging. The current evidence, including the results presented here, suggests a new paradigm of aging that recognizes diverse and often highly plastic aging processes that can be influenced by health interventions, behavioral changes, and environmental improvements and that depend on genetic differences both between and within species.

Sustained progress in reducing death rates at a rate of 1 percent per year would result in longer human life expectancy and a dramatic increase in the proportion elderly. Progress is most important at the ages when most deaths occur; the weighted average of age-specific rates of mortality improvement, with weights equal to the product of the number of deaths and remaining life expectancy, determines change in life expectancy (Vaupel 1986). Although remaining life expectancy at age 100 is only about two years, at age 80 it is close to a decade in most developed countries. Since half of female and a third of male deaths now occur after age 80 in developed countries, mortality reductions at older ages are crucial in determining change in life expectancy and the proportion elderly.

As a rule of thumb, an average annual rate of improvement of 1 percent at all ages would yield an increase of one year in life expectancy per decade; progress at a rate of 2 percent would yield a two-year increase per decade (Vaupel 1986). At current mortality levels a newborn girl in most developed countries has a life expectancy of about 80 years. If improvements in death rates could be maintained at an average rate of 1 percent per year, then her life expectancy would be about 90 years. Sustained 2 percent progress would imply that the typical newborn girl today in developed countries will live to celebrate her 100th birthday (Vaupel and Owen 1986; Vaupel and Gowan 1986).

Such an increase in female life expectancy and a corresponding increase in male life expectancy would multiply the numbers of persons at advanced ages. For instance, according to projections for the United States that assume 2 percent annual progress (Guralnik, Yanagishita, and Schneider 1988; Ahlburg and Vaupel 1990), the population above age 85 could increase from 3 million in 1990 to more than 70 million in 2080. This figure may be contrasted with estimates of 13, 18, and 26 million persons in the low, intermediate, and high projections of the US Social Security Administration (Wade 1992), all of which assume much lower rates of mortality reduction.

The future is uncertain and the distant future highly uncertain. Extrapolations of the effects of sustained 2 percent annual reductions in death rates help illustrate the range of uncertainty about future population structures; these simple extrapolations should not be given undue weight or attention. In the projections, as life expectancy approaches 100 further progress depends increasingly on reductions in death rates after age 100. Since very little evidence is available from which to estimate future trends in mortality among centenarians, the prospect that human life expectancy may approach or even exceed 100 within the lifetimes of children alive today should be viewed as one of a broad range of possibilities. Furthermore, that recent rates of progress in reducing mortality among the very elderly have run at 1 to 2 percent per year for females and 0.5 to 1.5 percent for males in most developed countries does not guarantee that future rates of improvement will be comparable, even in the near future. There may be obstacles to further lowering death rates among the oldest-old.

On the other hand, three findings presented here suggest that continued progress cannot be dismissed as implausible. For the industrialized countries in our study, (1) rates of mortality improvement at advanced ages have accelerated over the course of this century and particularly since 1950; (2) rates of improvement in countries with low levels of mortality have been approximately as great on average as rates of improvement in countries with higher levels of mortality; and (3) death rates in different countries and between males and females have not converged over time.

The possibility of a significant extension of life expectancy and of a radical increase in the population at advanced ages heightens the need to analyze whether and how the quality of these added years of life can be enhanced. The answer is central to forecasting the impact of population aging on health and social needs and costs, but very little is currently known about what the answer might be. Fries (1980) conjectured that morbidity is plastic and can be reduced so that the period of disability at the end of life is reduced to a year or two. Changes in lifestyle and reductions in risk factors can substantially reduce morbidity and mortality among the elderly (Manton, Stallard, and Tolley 1991). Furthermore, scattered evidence suggests that medical and public health interventions can improve health and well-being even after age 85 (Suzman et al. 1992; Rogers, Rogers, and Belanger 1989; Fiatrone et al. 1990; Applegate et al. 1990). There are also more pessimistic conjectures and strands of contradictory data (Crimmins, Saito, and Ingegneri 1989; Verbrugge 1984; Alter and Riley 1989).

"Every man desires to live long," Swift observed, "but no man would be old." If current trends continue, many of us may live well past 80. How many of us will live past 100 and how well we will live at advanced ages are two much more uncertain questions.

Notes

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1 Other databases in the Odense Archive of Population Data on Aging include highly reliable death counts and population counts for Sweden for single year of time since 1865 for ages 50 and older, compiled by Hans Lundström, and death counts and population counts for Denmark for single year of time since 1830 from birth to the oldest ages attained, compiled by Axel Skytthe and Kirill Andreev with considerable help from Ulla Larsen and Jens Lauritsen. The Archive also includes survival data on Danish twins born between 1870 and 1930 and on various nonhuman species. For information about use of the data in the Archive, write to James Vaupel, Odense University Medical School, Winsløwparken 17, DK-5000 Odense, Denmark.

2 Rosenwaike (1985), Coale and Kisker (1986, 1990), Condran, Himes, and Preston (1991), and Kestenbaum (1992) have analyzed the quality of US death and population counts at older ages. Perhaps the best estimates of US death rates at older ages are those calculated by Kestenbaum (1992), who demonstrates how sensitive such estimates are to the data and procedures used. His estimates of black death rates at older ages are substantially lower than his estimates of white death rates; Coale and Kisker (1986, 1990) argue that this is evidence of bad data. In addition, Kestenbaum's estimates of white death rates in the United States are 10 to 20 percent lower than death rates in Japan and Sweden. The United States may have exceptionally low mortality after age 80, but we believe that further research is needed to rule out the possibility of underestimation. In any case, Kestenbaum's estimates pertain only to 1987. No reliable estimates of US mortality after age 80, calculated using similar methods and data, are available over a period of a decade or more.

3 Values of the average annual rate of improvement in mortality were calculated as follows. The annual age-specific central death rate is given by

$$m(x,y) = \frac{D(x,y)}{(N(x,y)+N(x,y+1))/2},$$

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 1 January of year y. The average death rate in the interval from age x through x^* and year y through y^* can be calculated by:

$$\bar{m}\,(x,x^*,y,y^*) = \frac{\sum_{j=y}^{y^*}\sum_{i=x}^{x^*} w(i)m(i,j)}{\sum_{j=y}^{y^*}\sum_{i=x}^{x^*} w(i)}.$$

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 1950 through 1990:

$$w(i) = \frac{\sum_{y=1950}^{1990} (N_m(i,y)+N_f(i,y))}{\sum_{x=80}^{104}\sum_{y=1950}^{1990} (N_m(x,y)+N_f(x,y))},$$

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 article are values of $\bar{m}$. The average annual rate of improvement in death rates from the first period to the second period is given by:

$$\rho = -\left(\left(\frac{\bar{m}_2}{\bar{m}_1}\right)^{1/\delta} - 1 \right),$$

where δ is the interval between the means of the two periods:

$$\delta = \frac{(y_2 + y_2^* + 1)}{2} - \frac{(y_1 + y_1^* + 1)}{2},$$

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

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