The remarkable improvements in survival at older ages

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SUMMARY

The belief that old-age mortality is intractable remains deeply held by many people. Remarkable progress, however, has been made since 1950, and especially since 1970, in substantially improving survival at older ages, even the most advanced ages. The pace of mortality improvement at older ages continues to be particularly rapid in Japan, even though mortality levels in Japan are lower than elsewhere. The progress in improving survival has accelerated the growth of the population of older people and has advanced the frontier of human survival substantially beyond the extremes of longevity attained in pre-industrial times. Little, however, is known about why mortality among the oldest-old has been so plastic since 1950. The little that is known has largely been learned within the past few years. New findings, especially concerning genetic factors that influence longevity, are emerging at accelerating rate.

'There is one and only one cause of death at older ages. And that is old age. And nothing can be done about old age.' This paraphrase of a remark by Leonard Hayflick, a pioneering gerontologist, captures the gist of a prevalent syndrome of beliefs. Because deaths at younger ages are now unusual in developed countries, this view implies that human life expectancy in England and similar countries is close to the limit imposed by biology. The population of older people will grow as the baby boom ages, but if this view is correct governments need not worry that enhanced survival at older ages might accelerate the growth. Furthermore, the view that mortality at older ages is intractable leads to the conclusion that health-care resources and biomedical research should be not be wasted on hopeless attempts to prolong the lives of the elderly (Olshansky *et al*. 1990; Lohman *et al*. 1992).

Mortality at older ages is, however, by no means intractable. In fact, remarkable progress has been made since 1950 and especially since 1970 in substantially improving survival at older ages, even the most advanced ages. Despite this compelling evidence, the belief that old-age mortality is intractable remains deeply held by many people. Because of its implications for social, health, and research policy, the belief is pernicious. Because the belief is so prevalent, forecasts of the growth of the elderly population, expenditures on life-saving health care for the elderly, and expenditures for biomedical research on the deadly illnesses of old age are all too low.

The fact is that mortality at older ages has fallen dramatically since 1950 in developed countries. Figure 1 shows the progress that has been made in England and Wales for females aged 85, 90, and 95. Most older people are female, so for simplicity only female data are presented in most of the tables and figures of this review. Similar patterns to those shown in figure 1 exist in most other developed countries and for males, although male gains have generally been smaller than female gains (Kannisto 1994, 1996; Kannisto *et al*. 1994). The curves are jagged because population sizes at these ages are small and because of the impact of infectious-disease epidemics and other irregular factors. Between 1911 and 1950 or so, mortality improvements at older ages were slow, but after 1950 and especially after 1970 the improvements are impressive.

Figure 2 shows the pattern of mortality decline since 1950 for female octogenarians and nonagenarians in four representative countries: England & Wales, France, Sweden, and Japan. Japan shows a particularly impressive performance.

The pace of mortality improvement at older ages has been accelerating over recent decades. This is shown in figure 3 for male and female octogenarians and nonagenarians in an aggregation of nine countries (including England & Wales, and Scotland) with reliable data.

Another, longer-term perspective is provided in table 1, which documents the acceleration of mortality improvements for females in the Nordic countries of Denmark, Finland, Norway, and Sweden; countries for which reliable mortality data at older ages are available well back into the 19th century. Table 2 displays death rates by age and time for females in the Nordic countries. The increase in death rates with age is striking, as is the decrease in death rates over time.

If mortality is reduced, then the number of lives saved is proportional to the absolute decline rather than the relative decline. For instance, if the probability of death at some age is reduced from 20% to 15%, then an extra 5% of the population continue to enjoy life. In the last row of table 2, the absolute improvements in Nordic female mortality are displayed. It is at the most

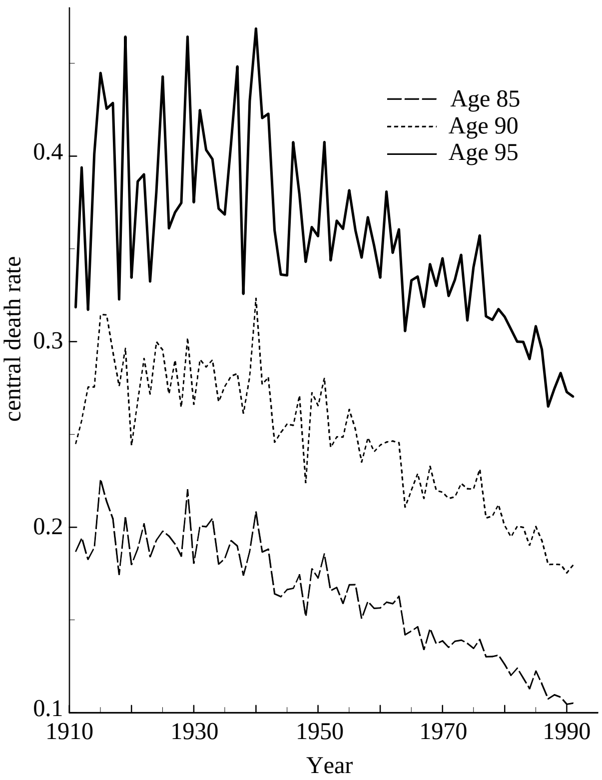

Figure 1. Improvements in mortality from 1911–1991 in England & Wales for females aged 85, 90, and 95. Source: compiled by author from data in the Kannisto–Thatcher oldest-old database, Odense University, Odense, Denmark.

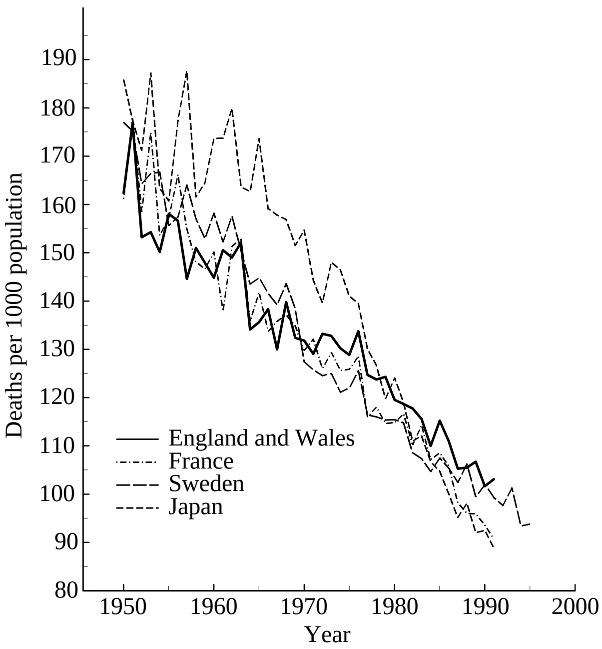

Figure 2. Mortality reductions since 1950 for female octogenarians and nonagenarians in England & Wales, France, Sweden, and Japan. Source: compiled by author from data in the Kannisto–Thatcher oldest-old database, Odense University, Odense, Denmark.

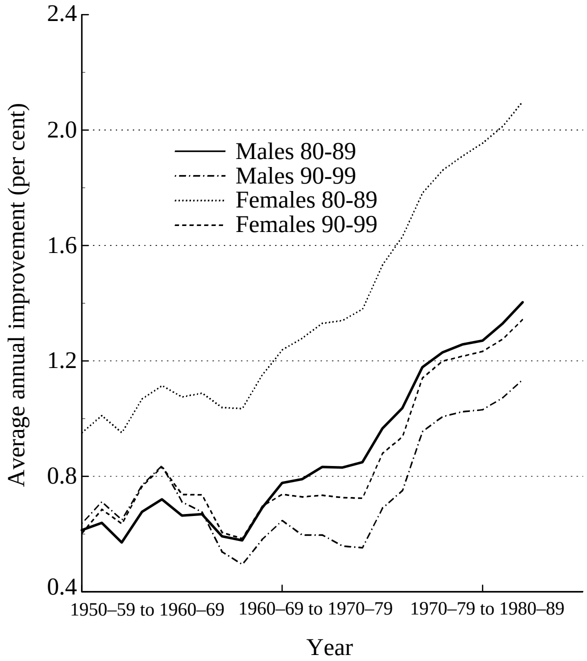

Figure 3. Average annual improvement in mortality between successive ten-year periods, for male and female octogenarians and nonagenarians, in an aggregation of nine countries. Source: compiled by author from data in the Kannisto–Thatcher oldest-old database, Odense University, Odense, Denmark. The nine countries are Austria, Belgium, England & Wales, France, West Germany, Japan, Scotland, Sweden, and Switzerland. The last point on the curves gives the rate of improvement between 1972–1981 and 1982–1991.

Table 1. *Average annual rates of improvement in female mortality (in %) for aggregation of Denmark, Finland, Norway and Sweden, for sexagenarians, septuagenarians, octogenarians, and nonagenarians, over successive periods 20 years apart*

(Source: calculations from death counts and population counts in the Odense archive of population data on aging (Kannisto 1994). See Kannisto *et al.* (1994) for a description of how average annual rates of improvement are calculated.)

	age category			
time period	60s	70s	80s	90s
1900s–1920s	0.3	0.2	0.1	0.0
1920s–1940s	0.7	0.4	0.2	0.0
1940s–1960s	1.7	1.0	0.6	0.5
1960s–1980s	1.5	2.1	1.7	1.2

advanced ages that the most lifesaving has occurred. On second thought, this may not seem so surprising because it is at the older ages that death rates are very high. Moreover, lives saved at the highest ages are generally not extended for more than a few years. Nonetheless, the large absolute reductions in mortality among centenarians and nonagenarians is a remarkable achievement, at sharp variance with the view that old-age mortality is intractable.

If death rates at older ages were approaching a biological limit, then it might be expected that improvements in countries with the lowest death rates would tend to be slower than in countries with death rates further away from the irreducible minimum. As

Table 2. *Female central death rates (in %) for aggregation of Denmark, Finland, Norway, and Sweden, for sexagenarians, septuagenarians, octogenarians, nonagenarians, and centenarians, in two periods, 1930–1949 and 1989–1993*

(Source: calculations from death counts and population counts in the Odense archive of population data on aging (Kannisto 1994). See Kannisto *et al.* (1994) for a description of how average annual rates of improvement are calculated.)

	age category				
time period	60s	70s	80s	90s	100s
1930–1949	2.4	6.4	16.1	33.9	70.1
1989–1993	1.1	3.1	9.1	23.4	48.5
change	1.3	3.3	7.0	10.5	21.6

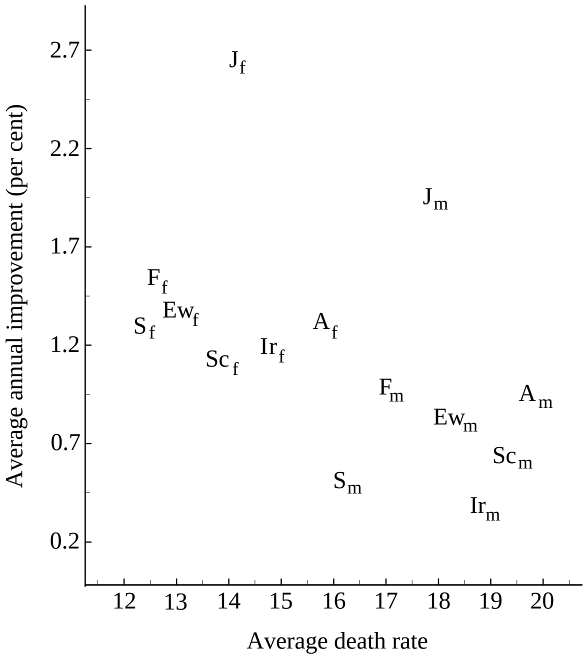

Figure 4. Average death rate in the 1970s compared with average annual improvement in mortality from the 1970s to the 1980s, for males and females, and for ages 80–99 combined. Note: f and m stand for female and male. The capital letters represent countries as follows: A, Austria; Ew, England & Wales; F, France; Ir, Ireland; J, Japan; S, Sweden; and Sc, Scotland. Source: compiled by author from data in the Kannisto–Thatcher oldest-old database, Odense University, Odense, Denmark.

illustrated in figure 4, however, there is no correlation, either for males or for females, between levels of mortality and rates of mortality improvement. Furthermore, males suffer higher mortality than females, but rates of improvements for females are higher than for males. Figure 4 only shows a few countries, but examination of many more countries yields the same result (Kannisto *et al.* 1994).

Much of the data used in the tables and figures so far comes from a database developed and compiled by Vaino Kannisto and Roger Thatcher (Kannisto 1994, 1996; Kannisto *et al.* 1994). This database includes most of the developed countries of the world, but not the United States. Until recently, demographers have been very wary of using U.S. mortality data at older ages because of concerns about the validity of age-reporting. New data sources, carefully checked by meticulous analysts, now permit accurate estimation of U.S. death rates, at least up to ages in the late 90s for the white population (Kestenbaum 1992; Shrestha & Preston 1995; Manton & Vaupel 1995).

Figure 5 compares some of these estimates with estimates for England & Wales and Sweden. The corresponding trajectories for France and Japan are very close to the Swedish curve. Two age-trajectories of white female mortality are shown for the United States, one for people from the Upper Midwest states of Minnesota and North and South Dakota (which is an area of exceptionally low mortality), and the other for people from the Deep South states of Arkansas, Louisiana, Mississippi, and Alabama (an area of relatively high mortality and an area in which age-misreporting might be particularly prevalent). Death rates in the Deep South remain above those in the Upper Midwest up to the late 90s: this suggests that the data may be reasonably reliable.

In both regions of the United States mortality is substantially lower than mortality in Western Europe and Japan. At age 90, for instance, death rates in Europe and Japan are almost 50% higher than in the Upper Midwest region of the U.S., 0.19 versus 0.13, and about 20% higher than in the Deep South region. This is remarkable because mortality before age 65 or 70 is substantially higher in the U.S. than in Western Europe and Japan. Because the very old particularly benefit from medical care and salubrious behaviour, it is possible that the U.S. advantage stems from better health conditions for the elderly. In any case, the gap between the U.S. on the one hand, and Western Europe and Japan on the other, is further evidence for the plasticity of mortality at older ages.

Let me now turn to the impact of mortality reductions on the growth of the elderly population, starting with the population of centenarians. In developed countries the number of centenarians is increasing at an exceptionally rapid rate, about 8% per year on average. Demographers are used to population growths rates of around 1% per year or so; an 8% growth rate seems more like an inflation rate. In England & Wales, an average of 74 persons per year reached age 100 between 1911 and 1920; by 1990 the number of people celebrating their 100th birthday had increased to almost 2000, and in 1997 the number will be around 3000 (Vaupel & Jeune 1995).

The population of centenarians is growing, in part, because of the increase in births a century ago, the sharp decline in infant and childhood mortality, and the substantial decline in mortality at ages from childhood up to age 80. Demographic analysis demonstrates, however, that by far the most important factor in the explosion of the centenarian population—two or three times more important than all the other factors combined—has been the decline in mortality after age 80 (Vaupel & Jeune 1995).

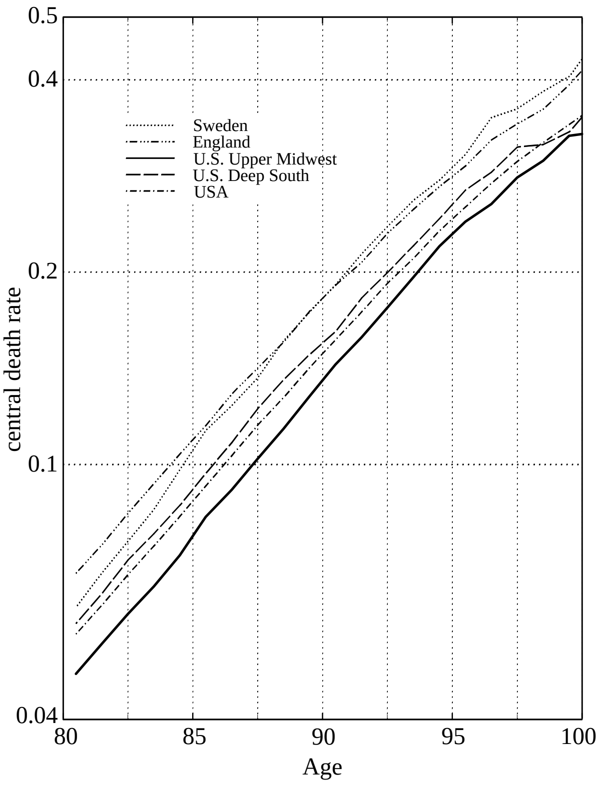

Figure 5. Mortality in England & Wales, Sweden, the United States, and two regions of the U.S.—the Upper Midwest and the Deep South—from age 80 to 99 in 1980–1989. Note: Mortality is measured by annual central death rates. For the U.S. the figures pertain to the white population. Source: for England & Wales and Sweden, compiled by author from data in the Kannisto–Thatcher oldest-old database, Odense University, Odense, Denmark. For the U.S. and the two U.S. regions, compiled by the author from data provided by the U.S. Social Security Administration. The Upper Midwest includes Minnesota and North and South Dakota. The Deep South includes Arkansas, Louisiana, Alabama, and Mississippi. People are classified by the region in which they were living when they received their social security numbers.

Increases in maximum human lifespans are also largely attributable to improvements in survival at the highest ages. Lundström (1995) carefully verified the ages of the oldest people who died in Sweden from 1860 through 1994. In the 30 years between 1860 and 1889, no one survived to age 106. Over successive decades, the maximum gradually rose, with the current Swedish record holder having died at age 112 in 1994. As argued by Jeune (1995), it is possible in Sweden (and other countries with modest populations) that no one attained the age 100 before 1800. There may have been a few scattered centenarians in earlier centuries, perhaps one per century somewhere or other in the world, perhaps even fewer (Wilmoth 1995), in contrast to the 100 000 centenarians who may be alive to welcome the year 2000 (Vaupel 1994). Wilmoth's (1995) analysis indicates that 'there were almost certainly no true super-centenarians (individuals aged 110 or above) prior to the mortality decline of the past two or three centuries.' Research by Peter Laslett and colleagues suggests that the first reasonably well-documented case of a super-centenarian is Katherine Plunket, who died at the age of 111 in 1932 (Jeune 1995). Jeanne Calment is the first carefully verified instance of a person reaching age 120 (Allard *et al.* 1994); she died at the age of 122 years and 5 months in August 1997.

Centenarians are still unusual and super-centenarians are a thousand-fold rarer, but these findings do illustrate the fact that mortality reduction can have major impacts on population growth at older ages and on extending the frontier of survival. The growth of the population of female octogenarians in England & Wales provides another telling example. The remaining life expectancy of 80-year-old females in England & Wales around 1950 was approximately six years. Currently the corresponding figure is about nine years, some 50% higher. As a result, the population of female octogenarians in England & Wales is roughly half again as big as it would have been if mortality *after age 80* had remained at 1950 levels. Putting this in terms of population counts, more than a half million females age 80+ are alive today in England & Wales who would have been dead if mortality after age 80 had not been reduced.

The figure of nine years for the remaining life expectancy of 80-year-old females in England & Wales is an estimate for 1997, based on data from Kannisto (1996), not a precise figure but good enough for illustrative purposes. Change in life expectancy is often (but not always) serviceable as a rough indicator of the impact of mortality reductions on population size; the required calculations to produce a more exact estimate are fairly complicated. See Kannisto (1996) or Vaupel & Jeune (1995) for details. Kannisto's calculations indicate that mortality improvements after age 80 in England & Wales between 1960 and 1990 (rather than 1950 and 1997) increased the female population by 250 000 persons.

Table 3 provides information about the size of the older population of various countries, from age 60 and up, for both sexes combined. Estimates are also given for the size of these populations in 2025. The projections assume slow improvements in mortality, so I believe that the estimates for 2025 are likely to prove to be low. Nonetheless, the size of the older population shows substantial increases, not only in Europe, but in Japan, the U.S., China, and India as well.

This worldwide growth in the population of older people heightens interest in a fundamental question: why do some people die at 60, more (in most developed countries) at 80, and a few at 100? Why is the chance of dying at 80 rather than 60 increasing and the chance of dying at 100 rapidly increasing (albeit from a very low level)? How important are genetic versus environmental, behavioural, and medical factors in determining how long an individual will live?

It might be expected that the answers to these questions—and the determinants of longevity more generally—are well understood. The duration of life has captured the attention of many people for thousands of years. Lifespans can be readily measured. Huge arrays of vital-statistics data for humans are available for many countries and for many centuries.

Table 3. *Proportion of population above age 60 (in %), and population above age 60 (in millions) for selected countries in 1996 and projected for 2025*

(Source: U.S. Bureau of the Census (1997).)

	%60 +		millions 60 +	
country	1996	2025	1996	2025
Italy	22	33	13	18
Germany	21	32	17	28
U.K.	21	29	12	17
France	20	30	12	18
Japan	21	33	26	40
U.S.A.	17	25	44	83
China	9	20	115	290
India	7	12	62	16

Masses of longevity and lifespan data are also available for thousands of other species.

A recent review, however, of the determinants of longevity (Christensen & Vaupel 1996) concludes that surprisingly little is known. The chance of reaching age 80 (or 90 or 100) is better for: (i) women than men, (ii) people born in this century rather than earlier, (iii) people born in developed countries, and (iv) people who have some favourable genes, such as the *ApoE 2* gene (Schächter *et al*. 1994). Smoking is certainly a health hazard at younger ages and probably at the oldest ages as well. Obesity may be a risk factor, and diet more generally is probably important. Some pharmaceuticals, such as dehydroepiandrosterone (DHEA), may increase survival at older ages. Studies of twins and other kinds of related individuals suggest that about 25% of the variation in adult lifespans appears to be attributable to genetic variation among individuals (McGue *et al*. 1993; Herskind *et al*. 1996). Some research in progress by two colleagues (Anatoli Yashin and Ivan Iachine) suggests that an additional 25% may be attributable to non-genetic characteristics that are more or less fixed by the time a person is 30 or so; characteristics such as educational achievement, socio-economic status, mother's and father's age at a person's birth, etc. Research on the relative importance for longevity of various candidate genes and non-genetic fixed attributes is, however, still at an early stage of development.

Barker's (1992, 1995) 'foetal-origins hypothesis' suggests that nourishment *in utero* and during infancy programs the development of risk factors for several important diseases of middle and old age. Other researchers have also concluded that nutrition and infections early in life have major effects on adult mortality (Kermack *et al*. 1934; Elo & Preston 1992; Fogel 1993). To the extent this is true, longevity may be determined by conditions in childhood and perhaps before birth. There is, however, conflicting evidence that suggests that current conditions (i.e., at older ages) may be more significant than conditions early in life. Kannisto (1994, 1996) finds current effects to be much more important than cohort effects on mortality after age 80. Christensen *et al*. (1995) find that from age 6 up to the oldest ages, twins (who tend to be born prematurely and at low birth weight) suffer the same age-specific death rates as singletons. And Kannisto *et al*. (1997) find 'no increased mortality in later life for cohorts born during famine'. Pinning down the nature and magnitude of possible lingering effects of early-life conditions on survival at advanced ages is an important research priority.

To conclude, let me reiterate the basic thrust of this review—over the past half century and especially in the most recent decades, remarkable improvements have been achieved in survival at older ages, including and along some dimensions especially at the highest ages. This progress has accelerated the growth of the population of older people and has advanced the frontier of human survival substantially beyond the extremes of longevity attained in pre-industrial times. The widely-held position that mortality at older ages is intractable is untenable. Little, however, is yet known about why mortality among the oldest-old has been so plastic since 1950. There is considerable (but still inadequate) knowledge of why some people die in infancy or childhood and why some people die prematurely at adult ages before age 60 or 70. Much less is known about why some people survive to age 80, others to age 90, and a few to age 100. The little that is known has largely been learned within the past few years and new findings (especially concerning genetic factors) are emerging at an accelerating rate. More research, especially in a country like England with a long and distinguished history of creative thinking and path-breaking insights, could provide vitally-significant knowledge.

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