Continued Reductions in Mortality at Advanced Ages

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Record life expectancy for women has been increasing by about 2.5 years for every decade since the mid-nineteenth century in countries where adequate records exist (Oeppen and Vaupel 2002). Initially, the largest contributions to this linear increase came from reductions in mortality among infants, children, and young adults. Since the 1950s, progress has been propelled by improvements at older ages. Under prevailing mortality regimes in countries with high life expectancy, future increases in the average length of life for both sexes depend on improving the survival chances of the elderly (Vaupel 1986; Vaupel and Yashin 1986).[1]

The prospect of prolonging life is a subject of wide interest to researchers. Kannisto et al. (1994), Kannisto (1994, 1996), and Vaupel et al. (1998) present evidence that death rates are declining at older ages and that current theory and empirical findings do not suggest a looming limit to life expectancy. Caselli and Vallin (2001: 61) come to a similar conclusion: "[N]ot only is there no proof that human longevity is an intractable constant, there is good evidence that its boundaries are not fixed." However, there is a wide range of opinion about the limits to human longevity, ranging from the contention that "[l]ife expectancy for humans … is unlikely to exceed 85 years (for men and women combined) unless it becomes possible to slow the rate of aging in a significant fraction of the population" (Carnes and Olshansky 2007: 375) to the "thousands of years" vision of Aubrey de Grey (e.g., de Grey 2006).

In this article, we investigate empirical trends in mortality at ages 80 and higher in developed countries to determine whether the observed survival improvements among the oldest-old (ages ≥80 years) are coming to a standstill, or whether progress is continuing along the trends described a decade ago by Kannisto (Kannisto et al. 1994; Kannisto 1994, 1996).

In the late 1980s and through most of the 1990s, Kannisto and colleagues documented and analyzed the improvements in mortality at old ages since the 1950s (Kannisto 1988, 1990, 1993, 1994, 1996; Kannisto et al. 1994; Thatcher et al. 1998). The numbers of octogenarians in 12 countries determined to have good data quality were found to have tripled between 1950 and 1990 for men and quadrupled for women. The population of nonagenarians grew by a factor of eight, and there were 22 times more centenarians alive in 1990 than in 1950. The number of women and men (combined) at ages 80 and above grew by a factor of four between 1950 and 1990 (Kannisto 1994: 22). This translates into an average annual increase of 3.47 percent in the number of the oldest-old during those four decades. The probability of dying at age 80 in 13 countries with good data quality during the 1950s was estimated to be 10 percent for women. Thirty years later, the probability had fallen to 6.23 percent (Kannisto 1996: 21). As shown in Kannisto et al. (1994) and Vaupel (1997), mortality at old ages did not simply decrease: starting in the 1970s, the pace of improvement began to accelerate. For example, the average annual improvement was about 0.8 percent when comparing data from the 1960s with the 1950s for octogenarian women in a group of 19 countries. Twenty years later, the corresponding improvement was 1.88 percent annually.

The database

The data used here are from the Kannisto–Thatcher Database on Old-Age Mortality (KTDB). The database contains population and death counts for women and men aged 80 and older for more than 30 countries. The database was initiated in the late 1980s by Väinö Kannisto, the former United Nations advisor on demographic and social statistics, to address a lack of reliable and internationally comparable information on old-age mortality. Roger Thatcher, former Director of the Office of Population Censuses and Surveys and Registrar-General of England and Wales, soon joined Kannisto in this effort. In the early 1990s, their data collection was computerized at Odense University Medical School, Denmark. Since 1997 the Max Planck Institute for Demographic Research in Rostock, Germany, has hosted, maintained, and updated the database. The database is freely accessible at http://www.demogr.mpg.de/databases/ktdb/.

One of the major advantages of the KTDB is that its creators and database managers applied the same methods for every country in order to provide comparable mortality estimates. Population data are usually less reliable than information on deaths at advanced ages. Based on death counts by sex, age at death, year of death, and year of birth, cohort survival histories are constructed using extinct cohort and survivor ratio methods (Vincent 1951; Depoid 1973; Thatcher et al. 2002).

Ensuring high data quality and comparability across countries has been of prime concern since the establishment of the database. Jdanov et al. (2008) analyzed data quality for the countries documented in the KTDB by applying a battery of tests (e.g., an age heaping index) and proposed a classification of countries according to their data quality. Generally speaking, data quality for every country examined improved over calendar time, with the exception of Chile. Table 1a provides the numbers of persons at advanced ages for the years 1950, 1960, 1980, 1990, 2000, and 2004 for all countries in the KTDB, sorted into four categories according to data quality for the interval 1991–2000, as categorized by Jdanov et al. (2008). The majority of the countries examined have at worst "acceptable data quality," which means that, while their data show some problems, the data describe the mortality trends of the country generally correctly (Kannisto 1996). Canada and the United States systematically show weak or conditionally acceptable data quality up to the 1990s, and Chile has the poorest data quality. In addition, Ireland, Lithuania, New Zealand (Non-Maori), Portugal, and Spain showed weak data quality during some decades between the 1950s and the 1970s.

It might appear that some of our results for previous periods differ from the results published in Kannisto et al. (1994). Discrepancies have arisen because, in the KTDB, counts are re-calculated backward using the most recent data. In some cases, the data that were previously available in the KTDB were replaced by revised official estimates. A detailed explanation of the construction and estimation of the data is provided on the webpage of the KTDB.

Population counts

A rough measure of improvements in mortality is the change in population counts at older ages. This measure, while crude, provides an important perspective for policymakers on the growing number of the elderly and the impact this increase may have on many aspects of society. Since the study by Kannisto et al. (1994), data have become available for more years and more countries. Table 1b uses the same numbers as in Table 1a and expresses them as the proportion of the total population (per 100 for ages 80–99 and per 1,000 for centenarians).

The trends previously observed by Kannisto et al. (1994) have persisted: while centenarians were rare in the 1950s and 1960s, about 30,000 persons were aged 100 years or older in 1980. In subsequent decades, this number increased by about 30,000 persons from 1980 to 1990, and by 40,000 from 1990 to 2000. At current rates, it will take less than ten years to add another

TABLE 1a Population at advanced ages as of 1 January 1950, 1960, 1980, 1990, 2000, and 2004

	Ages 80–99						Ages 100+					
Country[a]	1950	1960	1980	1990	2000	2004	1950	1960	1980	1990	2000	2004
A.												
Belgium	120,567	169,511	255,268	341,887	355,091	—	20	42	163	491	845	—
Denmark	51,656	73,390	142,109	188,242	208,590	218,617	17	19	156	325	470	596
Finland	28,529	40,582	81,903	138,415	170,877	195,120	4	12	42	133	239	326
France	653,899	908,007	1,493,549	2,080,535	2,123,419	2,613,026	195	368	1,895	3,926	7,910	11,020
Germany	—	1,150,852	2,004,203	2,911,886	2,795,356	3,305,326	—	151	975	2,463	5,687	7,468
Germany (West)	—	836,014	1,555,329	2,368,070	2,300,088	2,718,394	—	117	746	2,230	4,826	6,164
Italy	—	673,943	1,218,882	1,827,662	2,266,801	2,758,217	—	252	880	2,378	5,432	7,608
Japan	357,431	639,257	1,538,230	2,805,722	4,623,289	5,690,690	111	156	927	3,055	11,493	21,713
Netherlands	99,853	155,277	309,024	432,619	506,425	556,747	37	62	391	814	1,400	1,433
Norway	55,327	70,063	117,153	155,938	189,539	208,672	48	73	154	296	422	484
Poland	—	—	495,174	754,283	742,676	910,385	—	—	456	766	1,059	1,609
Sweden	106,751	137,885	254,080	358,366	435,392	474,661	46	73	308	570	900	1,191
Switzerland	52,378	80,664	160,900	243,657	287,005	318,290	10	29	124	333	675	879
B.												
Australia	—	—	241,168	357,853	554,082	670,137	—	—	412	955	1,465	1,916
Austria	79,954	121,159	196,951	270,869	269,811	—	17	25	108	203	437	—
Czech Republic	86,421	112,359	187,751	247,546	231,446	292,635	9	17	88	91	172	222
England and Wales	646,554	894,569	1,335,047	1,831,231	2,084,279	2,321,660	265	531	2,136	3,869	5,895	7,778
Estonia	—	19,239	32,027	39,195	36,361	40,308	—	10	44	59	52	32
Germany (East)	—	314,810	448,902	545,185	496,938	586,884	—	30	216	233	888	1,319

Hungary	80,196	108,207	207,866	263,516	261,357	—	19	37	70	137	284	—
Iceland	—	—	5,005	6,306	7,441	8,689	—	—	6	17	24	27
Ireland	43,270	58,126	64,797	77,428	95,143	—	30	28	66	112	161	—
Latvia	—	37,304	58,031	74,323	61,936	67,346	—	55	106	155	129	135
Lithuania	—	—	73,654	96,884	82,883	97,463	—	—	372	571	298	326
Luxembourg	—	—	7,848	11,029	12,365	—	—	—	14	22	10	—
New Zealand	22,085	35,857	52,371	74,261	105,409	122,965	52	40	86	240	289	378
New Zealand (Non-Maori)	21,424	35,199	51,882	73,345	103,303	120,281	14	16	80	237	284	367
Portugal	85,504	107,467	173,756	271,285	337,208	384,067	224	107	127	319	489	528
Scotland	66,198	84,331	123,972	167,764	184,906	203,128	27	37	140	286	427	559
Slovakia	—	37,514	71,210	98,515	95,391	121,731	—	19	35	31	81	76
Slovenia	—	—	43,551	44,986	—	—	—	—	18	40	—	—
Spain	279,853	368,219	682,553	1,130,470	1,521,454	1,765,535	438	432	1,277	2,403	3,431	5,162
C.												
Canada	149,069	222,648	426,451	613,374	878,637	—	155	240	1,211	2,632	3,323	—
United States	—	2,545,048	5,036,929	6,854,101	9,325,677	10,369,285	—	5,354	15,106	29,948	41,342	50,471
D.												
Chile	—	95,613	152,009	234,623	—	—	669	366	732	—	—	—
Total	3,086,919	10,037,501	19,199,588	27,907,322	34,030,184	37,140,259	1,738	8,332	29,586	60,684	101,611	129,787

[a]Countries are grouped according to four categories (designated A, B, C, and D) of decreasing data quality for the period 1991–2000 as given in Jdanov et al. (2008).
NOTES: The symbol "—" indicates that no data were available for the specific country on 1 January of the given year.
The Totals omit the entries for Germany (West), Germany (East), and New Zealand (Non-Maori).
SOURCE: KTDB.

TABLE 1b Proportion of population at advanced ages as of 1 January 1950, 1960, 1980, 1990, 2000, and 2004

	Ages 80–99 (per 100 population)						Ages 100+ (per 1,000 population)					
Country[a]	**1950**	**1960**	**1980**	**1990**	**2000**	**2004**	**1950**	**1960**	**1980**	**1990**	**2000**	**2004**
A.												
Belgium	1.40	1.87	2.60	3.45	3.46	4.11	0.003	0.005	0.019	0.052	0.083	0.110
Denmark	1.22	1.61	2.77	3.67	3.91	4.04	0.004	0.004	0.031	0.063	0.088	0.110
Finland	0.72	0.92	1.72	2.78	3.30	3.74	0.001	0.003	0.009	0.027	0.048	0.064
France	1.57	2.00	2.78	3.68	3.62	4.34	0.005	0.008	0.035	0.070	0.137	0.178
Germany	—	—	—	—	3.46	4.06	—	—	—	—	0.069	0.091
Germany (West)	—	1.51	2.53	3.78	3.51	4.09	—	0.002	0.012	0.036	0.072	0.091
Italy	1.03	1.36	2.20	3.21	3.95	4.76	0.002	0.005	0.016	0.042	0.095	0.127
Japan	0.44	0.69	1.33	2.29	3.68	4.51	0.001	0.002	0.008	0.025	0.092	0.169
Netherlands	1.00	1.36	2.19	2.86	3.14	3.42	0.004	0.005	0.028	0.055	0.067	0.077
Norway	1.71	1.97	2.79	3.64	4.23	4.56	0.015	0.022	0.038	0.059	0.094	0.105
Poland	—	0.67	1.40	1.99	1.95	2.38	—	0.002	0.013	0.024	0.028	0.044
Sweden	1.53	1.85	3.06	4.20	4.91	5.29	0.007	0.001	0.037	0.067	0.101	0.130
Switzerland	1.12	1.52	2.55	3.64	3.99	4.31	0.002	0.006	0.020	0.050	0.094	0.119
B.												
Australia	1.24	1.26	1.65	2.10	2.88	3.33	0.020	0.017	0.028	0.056	0.077	0.094
Austria	1.16	1.73	2.61	3.54	3.40	4.08	0.003	0.004	0.014	0.027	0.054	0.079
Czech Republic	0.97	1.18	1.83	2.40	2.27	2.87	0.001	0.002	0.010	0.008	0.017	0.025
England and Wales	1.48	1.95	2.69	3.62	3.99	4.38	0.006	0.012	0.042	0.075	0.110	0.138

Estonia	—	1.59	2.16	2.52	2.68	2.99	—	0.007	0.030	0.031	0.039	0.050
Germany (East)	—	1.82	2.68	3.31	3.23	3.93	—	0.002	0.014	0.014	0.059	0.090
Hungary	0.86	1.09	1.94	2.53	2.57	3.23	0.002	0.004	0.007	0.015	0.025	0.036
Iceland	1.49	1.42	2.20	2.49	2.67	2.99	0.032	0.028	0.027	0.067	0.093	0.093
Latvia	—	1.77	2.31	2.79	2.60	2.92	—	0.018	0.045	0.061	0.055	0.063
Lithuania	—	1.13	2.15	2.62	2.24	2.64	—	0.101	0.106	0.158	0.091	0.098
Luxembourg	—	1.50	2.12	2.90	2.84	3.10	—	0.004	0.007	0.008	0.027	0.042
New Zealand	1.17	1.52	1.66	2.18	2.74	3.05	0.034	0.023	0.027	0.071	0.075	0.094
New Zealand (Non-Maori)	1.20	1.60	1.81	2.42	3.15	3.52	0.009	0.009	0.028	0.078	0.087	0.108
Portugal	1.03	1.22	1.78	2.73	3.30	3.66	0.028	0.013	0.014	0.029	0.052	0.073
Slovakia	0.85	0.91	1.44	1.88	1.78	2.27	0.005	0.002	0.008	0.007	0.016	0.022
Slovenia	—	—	—	2.18	2.26	2.85	—	—	—	0.009	0.029	0.039
Spain	1.01	1.23	1.82	2.91	3.80	4.16	0.018	0.020	0.026	0.058	0.077	0.118
C.												
Canada	1.10	1.26	1.75	2.23	2.88	3.30	0.014	0.015	0.047	0.094	0.108	0.122
United States	1.13	1.43	2.23	2.75	3.29	3.51	0.028	0.030	0.067	0.121	0.145	0.154
Total	1.07	1.34	2.07	2.81	3.40	3.87	0.013	0.015	0.037	0.071	0.103	0.131

[A]Countries are grouped according to three categories (designated A, B, and C) of decreasing data quality for the period 1991–2000 as given in Jdanov et al. (2008).
NOTES: The symbol "—" indicates that no data were available for the specific country on 1 January of the given year.
Countries from Table 1a that are not part of the KTDB (Chile, Ireland, Scotland) have been omitted.
The Totals omit the entries for Germany (West), Germany (East), and New Zealand (Non-Maori).
SOURCE: Human Mortality Database.

40,000 centenarians: in only four years, from 2000 to 2004, a net addition of 28,000 centenarians has been recorded, despite the lack of numbers for some countries. The corresponding proportions in Table 1b look less dramatic, with about 0.1 centenarians per 1,000 population in the year 2000. Yet the magnitude of the growth of persons aged 100 years or older might be better appreciated by way of a simple example. For example, in Italy, there were 0.002 centenarians per 1,000 population in the year 1950. This means that a city with half a million inhabitants could expect to have one centenarian. With 0.127 centenarians per 1,000 in the year 2004, the corresponding population size was 7,874—the equivalent of a small town.

The number of octogenarians and nonagenarians is equally impressive. In many countries, as shown in Table 1b, this age range accounts for 4 percent to 5 percent of the entire population. Adding up the data, we calculated that in 2004 there were about 37 million persons aged 80 to 99 in the KTDB countries, or roughly twice as many people in this age range as were living just a quarter century earlier. The United States alone counted more than 10 million persons aged 80–99 in 2004, a number that is larger than the total population of New York City or Sweden.

Population counts provide only an indication that improvements in mortality have occurred, as such counts are also affected by the initial size of the birth cohort. Furthermore, numbers at a certain age are necessarily the outcome of the preceding mortality experience of these cohorts; for example, if a country had engaged in war, some cohorts of men might be substantially smaller at later ages, even if the number of births had been constant over time. Third, whereas migration is rare at ages 80 and higher, countries like the United States experience substantial immigration at younger ages. To control for these factors, we analyzed survival probabilities, remaining life expectancy at age 80, and the annual rate of decrease of death rates over time.

Survival probabilities

Figure 1 depicts survival probabilities from age 80 to age 90 (upper two panels), and from age 90 to age 100 (lower panel) for women (left column) and men (right column), in six selected countries from the KTDB from 1950 until the most recent available year. The six countries have been chosen to illustrate the diverse trends observed during the second half of the twentieth century and the first few years of the twenty-first. The remaining countries of the KTDB are given as gray lines. Table 2 accompanies Figure 1, giving average values (mean and median) and extreme values (minimum and maximum) for the survival probabilities from Figure 1 at the beginning and end of the observation period.

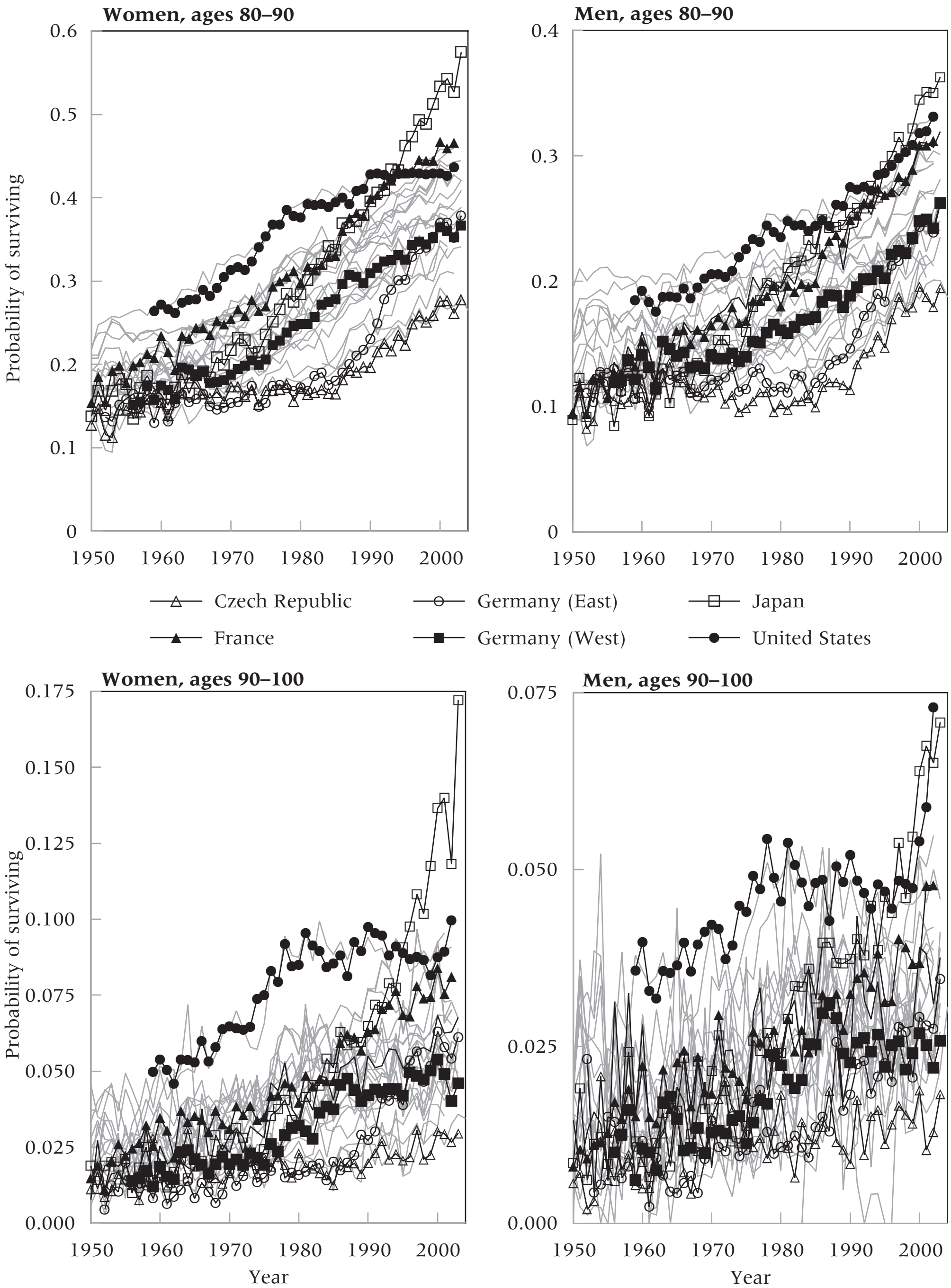
The probability that a person would live to see his or her 90th birthday after reaching age 80 was around 12 percent for men and 16 percent

TABLE 2 Probabilities of surviving (in percent) from age 80 to age 90 and from age 90 to age 100 in 1950 and 2002: Average and extreme values for men and women

Probability of surviving	From age 80 to age 90		From age 90 to age 100	
	Men	Women	Men	Women
1950				
Minimum	8.95 (Japan)	12.74 (Czech Republic)	0.14 (Finland)	0.61 (Hungary)
Maximum	19.42 (Norway)	22.21 (Norway)	2.23 (Canada)	4.55 (Portugal)
Mean	12.35	16.58	1.30	1.89
Median	11.50	15.35	1.49	1.66
2002				
Minimum	17.93 (Czech Republic)	26.13 (Czech Republic)	1.28 (Czech Republic)	2.55 (Estonia)
Maximum	35.04 (Japan)	52.66 (Japan)	7.32 (Iceland)	11.82 (Japan)
Mean	26.06	37.81	3.63	6.00
Median	24.68	38.16	3.10	5.81

NOTE: Calculation for 1950: 20 countries; 2002: 23 countries.
SOURCE: KTDB.

FIGURE 1 Probabilities of surviving from age 80 to age 90 (upper two panels) and from age 90 to age 100 (lower two panels) for women (left column) and men (right column) in selected KTDB countries



NOTE: Gray lines indicate all other KTDB countries except Chile, Estonia, Iceland, Latvia, Lithuania, and Luxembourg (omitted because of small population size or data problems).

for women in 1950. Just over 50 years later, those values had more than doubled to 25 percent for men and 38 percent for women. Highest survival probabilities in 2002 were recorded in Japan for both sexes. Out of 100 Japanese women who celebrate their 80th birthdays, more than 50 can expect to celebrate ten additional birthdays. Among Japanese men, the number is somewhat lower at 35, but is on a comparable level with the average across all countries for women. Those numbers are even more remarkable given that death rates in Japan were among the highest during the beginning of our observation period.

Two countries from the former Eastern Bloc, the former East Germany and the Czech Republic, deviate in their pattern from the mainstream: until the late 1980s, survival probabilities in these countries were among the lowest across all countries in the KTDB. Marked changes in survival probabilities did not occur in either country until 1990. Whereas the Czech Republic still performs very poorly among the KTDB countries despite the positive changes since 1990, East Germany caught up to West Germany in about one decade. The former East Germany now belongs to the mainstream group of countries in the KTDB with respect to survival probabilities from age 80 to age 90.

A negative trend can be observed among women in the United States since the late 1980s. American women aged 80 were then world leaders in survival. Since the late 1980s, however, the United States has lost its prime position, showing almost no further improvements. Similar signs of deceleration of mortality declines, or even periods of stagnation in mortality, have been observed for Dutch men and women, Danish women, and Norwegian men (not explicitly shown in Figure 1). Despite the aforementioned few exceptions, the majority of KTDB countries, primarily in Western Europe, followed similar paths during the last 25 years, with continued improvements in the probabilities of surviving from age 80 until age 90, most remarkably in France.

The lower two panels depict the probabilities of surviving from age 90 until age 100. Because of smaller population sizes at those ages, results tend to show more erratic patterns. Nevertheless, the general trends appear to be comparable to those for women and men aged 80, albeit on a very different level (see also right column of Table 2). On average, fewer than two persons out of 100 who had reached age 90 in 1950 went on to become centenarians. In 2002, the probabilities were slightly higher than 3 percent for men and about 6 percent for women. Japan once again rose near to the top from a disadvantaged position in 1950: the probabilities of surviving from age 90 to age 100 were 6.5 percent for men and 11.8 percent for women. Among men, the United States is still among the best-performing countries. We can see, however, the same development for American women in their 90s as in the upper part of Figure 1. Although this group long had the highest chances of reaching age 100 after reaching their 90th birthdays, their survival rates started to stagnate in the 1980s. Results for the Czech Republic and East Germany replicate our previous findings: the former East Germany caught up to West Germany, while the chances of survival remained relatively low among Czechs compared to the other countries included in the KTDB.

TABLE 3 Life expectancy at age 80 for all KTDB countries, 1960 and 2000 (years)

	Men			Women		
Country	1960	2000	Increase from 1960 to 2000	1960	2000	Increase from 1960 to 2000
Australia	—	7.89	—	—	9.64	—
Austria	5.23	7.06	1.83	6.03	8.54	2.51
Belgium	5.61	6.80	1.19	6.31	8.66	2.35
Canada	6.26	7.62	1.36	7.25	9.53	2.28
Chile	—	7.83	—	—	9.14	—
Czech Republic	5.02	6.12	1.10	5.72	7.25	1.53
Denmark	5.89	6.80	0.91	6.19	8.55	2.36
England and Wales	5.32	7.11	1.79	6.48	8.73	2.25
Estonia	5.35	6.15	0.80	6.28	7.66	1.38
Finland	5.35	6.79	1.44	5.62	8.48	2.86
France	5.61	7.68	2.07	6.72	9.77	3.05
Germany	5.36	6.90	1.54	5.86	8.45	2.59
Germany (East)	5.20	6.78	1.58	5.66	8.47	2.81
Germany (West)	5.43	6.92	1.49	5.94	8.45	2.51
Hungary	5.24	6.39	1.15	5.77	7.44	1.67
Iceland	—	8.01	—	—	9.41	—
Ireland	5.36	6.32	0.96	6.16	7.92	1.76
Italy	5.61	7.59	1.98	6.32	9.42	3.10
Japan	4.83	8.15	3.32	5.75	10.81	5.06
Latvia	5.94	6.03	0.09	6.75	7.18	0.43
Lithuania	—	6.77	—	—	7.80	—
Luxembourg	—	6.94	—	—	8.75	—
Netherlands	6.11	6.46	0.35	6.62	8.42	1.80
New Zealand	5.94	7.37	1.43	6.88	9.37	2.49
New Zealand (non-Maori)	5.93	7.38	1.45	6.85	9.40	2.55
Norway	6.13	6.92	0.79	6.68	8.79	2.11
Poland	—	6.44	—	—	7.67	—
Portugal	5.17	6.85	1.68	6.14	8.17	2.03
Scotland	5.01	6.82	1.81	5.90	8.38	2.48
Slovakia	5.55	6.04	0.49	5.96	7.08	1.12
Slovenia	—	6.53	—	—	8.12	—
Spain	5.68	7.7	2.02	6.64	9.33	2.69
Sweden	5.91	7.22	1.31	6.35	8.93	2.58
Switzerland	5.67	7.67	2.00	6.38	9.38	3.00
United States	6.12	7.75	1.63	7.23	9.27	2.04

"—" indicates that no data were available for the specific country for the given year.
SOURCE: Authors' estimates based on KTDB.

Life expectancy at age 80

The estimates of life expectancy at age 80 presented in Table 3 show the remarkable improvements in survival at older ages from a slightly different perspective. We have included all KTDB countries and listed them alphabetically.

In 1960, life expectancy for men at age 80 ranged, with few exceptions, between five and six years. Forty years later, men could expect to live on average seven more years after their 80th birthday. Latvia's life expectancy among men more or less stagnated. The Netherlands also saw comparably modest gains, its ranking among KTDB countries falling substantially over the four decades. The largest gain, 3.3 years, was recorded in Japan, where life expectancy for men at age 80 was 8.15 years in 2000.

Life expectancy for women at age 80 rose from an average of 6.3 years in 1960 to 8.5 years in 2000. Latvia and Japan experienced the smallest and greatest improvements among women, as they did among men.

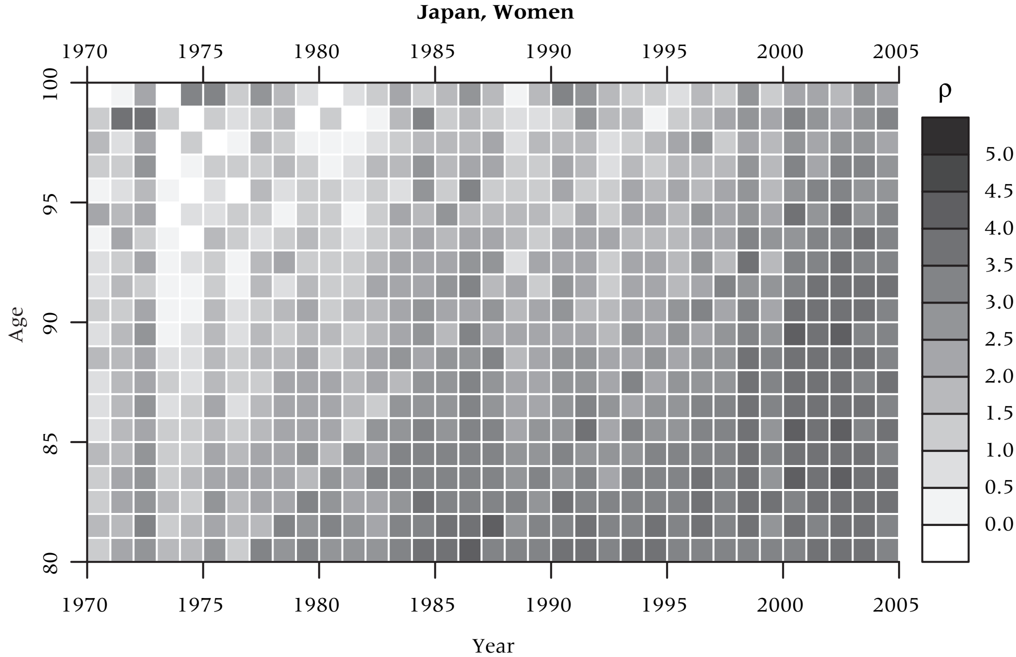
In the latest KTDB estimates, for 2006, life expectancy at age 80 reached 8.47 years for Japanese men and 11.32 years for Japanese women, exceeding the figures reported in Table 3.

Rates of mortality improvement

We track the dynamics of mortality change using average annual percent improvements in death rates over the preceding ten years.[2] In Figures 2–4, we use Lexis maps (Vaupel et al. 1997) to depict these improvements for single years and ages. For example, the gray tone of the lowest square on the left in the upper panel of Figure 2 indicates that death rates at age 80 for Japanese women dropped on average between 1960 (ten years earlier) and 1970 by 1.0–1.5 percent per year (see scale on the right hand side of each figure). We chose women in Japan and the former East Germany (Figure 2) as examples of rapid mortality change in recent decades. The dynamics in these two cases are, however, seen to be considerably different. With the shift toward darker shades of gray in the lower right triangle, it seems that in the case of Japanese women (upper panel in Figure 2) "vanguard" cohorts were setting the pace throughout the 1980s and 1990s. One can see that progress in successive years is maintained. During the last five years of our observation period (2000–2004), rapid improvements were experienced in the whole 80+ age range. The median value of improvements was never lower than 3.3 percent annually. Mortality dropped on average by around 3 percent per year even at ages 90 and higher, an age range in which improvements in other countries in the database were rather modest. If improvements maintain the pace of about 3 percent every year, death rates for nonagenarians would be halved in less than 23 years.

The dynamics observed for women in the former East Germany are very different: mortality improvements began to stagnate in the 1960s, as shown in previous tables and figures, and also by white and pale gray rectangles in

FIGURE 2 Average annual percent declines in age-specific death rates for ages 80–99 over the preceding 10 years (ρ), Japan and (former) East Germany, 1970–2005



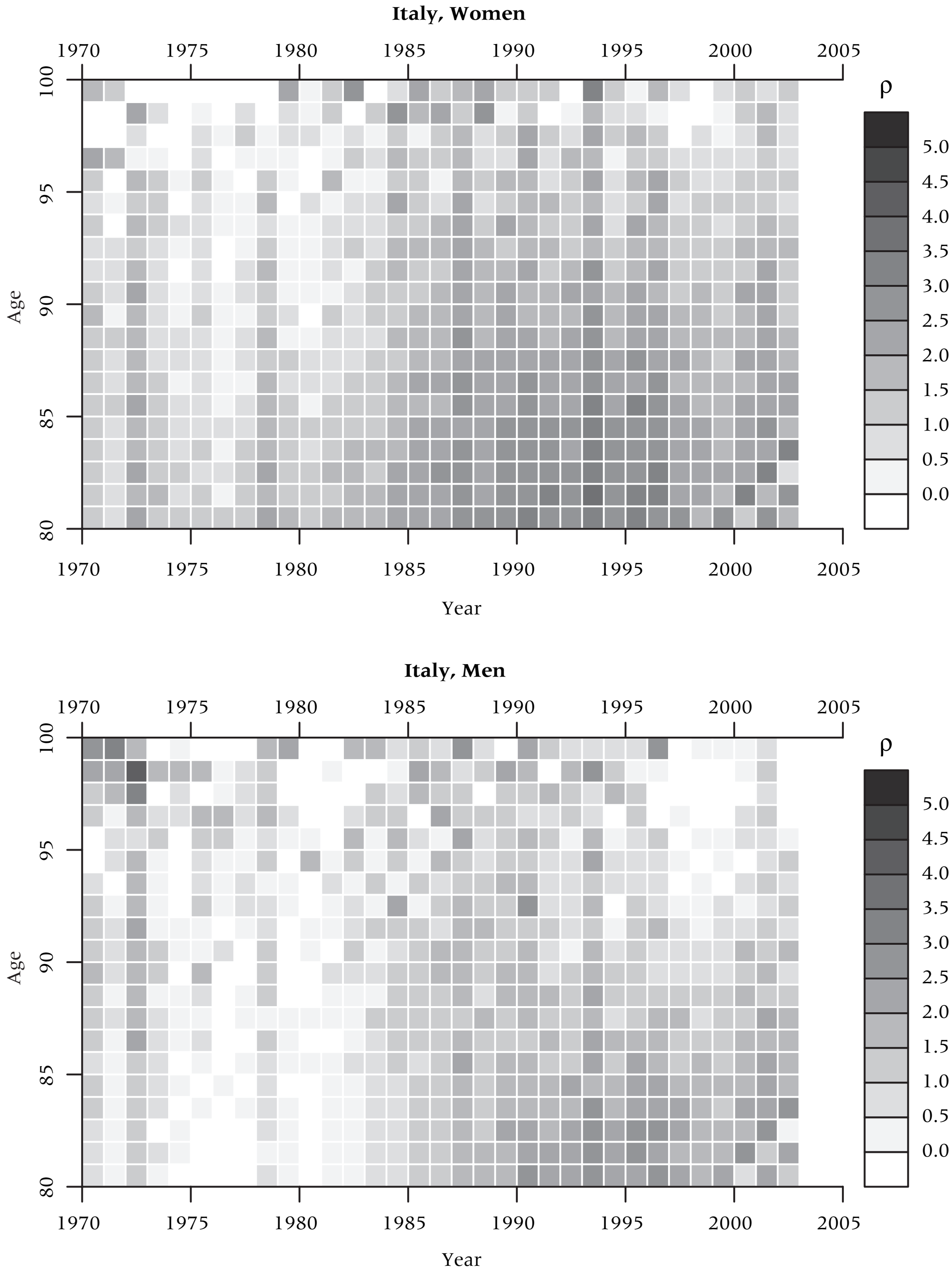
SOURCE: Authors' estimates based on KTDB.

the lower part of Figure 2. German reunification in 1990 not only brought substantive changes in the political system; it is also associated with a decrease in death rates among the oldest-old. Mortality change follows a clear period pattern. The strongest improvement came in the mid-1990s. It should come as no surprise that the pace subsequently slackened: the first ten years after reunification can be considered a period of "catching up" to western Germany. Since about 2002, mortality has continued to decline in eastern Germany but not at an accelerating rate. Because mortality levels in the new century in eastern and western Germany have been roughly similar, the rates of improvement in the former East Germany are no longer as exceptional as they were in the 1990s.

It was, however, not just the frontrunner, Japan, or countries benefiting from far-reaching changes in society, like the former East Germany, that were capable of substantially lowering oldest-old mortality. In Figure 3, we depict the results for Italy, a country that never had the world's highest life expectancy at birth, but never trailed far behind the record holder during the second part of the twentieth century. For women, the 1990s in particular brought many improvements in mortality, especially for octogenarians, whose death rates dropped at an annual rate of approximately 2.4 percent. During the last few years of our observation window, the annual rate of improvement slowed slightly to about 2 percent for these women. However, there are encouraging signs that mortality is now also consistently decreasing at the highest observed ages (90–99) among Italian women. The lower panel in Figure 3 shows the equivalent pattern for Italian men. Generally speaking, mortality improvements happened at a slower pace among men than among women, as indicated by the lighter shades of gray. Furthermore, the decrease in mortality among the oldest-old men started at a later point in time. Until the mid-1980s, improvements in mortality among Italian men aged 80 and higher were virtually nonexistent. As was the case among women, the 1990s brought substantial improvements in mortality for octogenarian men, albeit at a slower pace (1.8 percent per year).

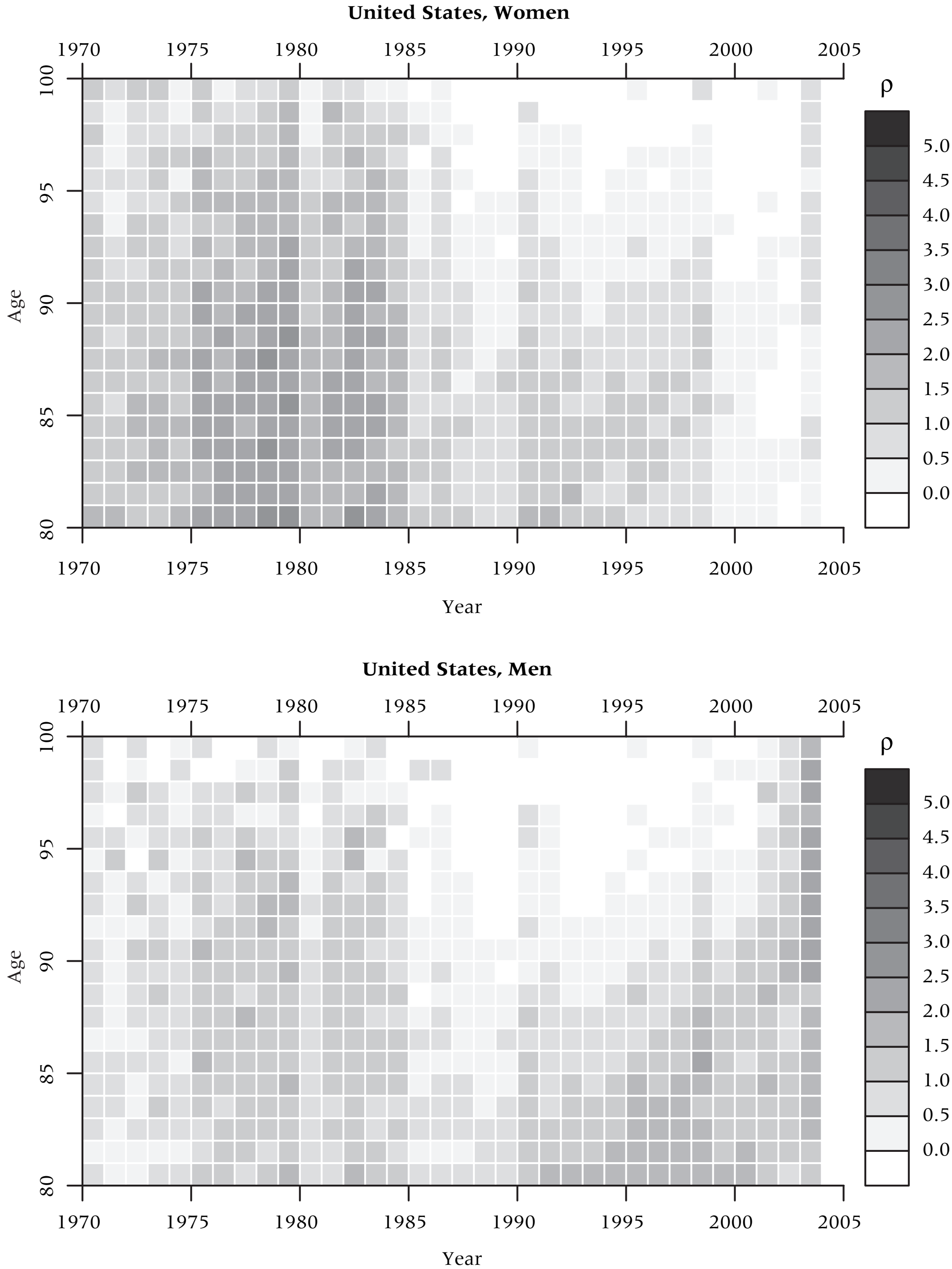
Impressive improvements in survival among the oldest-old are not a universal phenomenon in the primarily highly developed countries of the Kannisto–Thatcher Database. The most prominent exception is the United States, with other countries such as Denmark and the Netherlands displaying similar patterns. Until the 1980s, mortality among Americans in their 80s appears to have been exceptionally low (Shrestha and Preston 1995). Trends since the 1970s among women and men aged 80 to 99 in the United States are shown in Figure 4. Women's survival chances improved in the late 1970s, averaging around 2.2 percent annually for octogenarians. Yet during the 1980s, a decade that saw unprecedented survival improvements in many countries, mortality dropped at a rate of less than 1.4 percent among American women in their 80s. In addition, no improvements are detectable

FIGURE 3 Average annual percent declines in age-specific death rates for ages 80–99 over the preceding 10 years (ρ), Italy, 1970–2003



SOURCE: Authors' estimates based on KTDB.

FIGURE 4 Average annual percent declines in age-specific death rates for ages 80–99 over the preceding 10 years (ρ), United States, 1970–2004



SOURCE: Authors' estimates based on KTDB.

for American women in their 90s since the mid-1980s. In the new millennium, the stagnation in the trend toward lower mortality has even spread to women in their 80s, with almost no improvements occurring after 1999 among women aged 80 and above in the United States. Until the mid-1990s, the general picture was similar for American men (lower panel of Figure 4): from about 1975 to 1985 there were improvements all across the observed age range, after which they became very modest until 1995. Subsequently the trends among women and men have diverged: whereas mortality has remained constant among women, the situation for men has become more favorable, with improvements again accruing at the highest ages.

Summary and discussion

Our article has described developments in mortality among the oldest-old using data from the Kannisto–Thatcher Database on Old-Age Mortality. This database does not rely on official mortality statistics, but uses information on the number of deaths by age at death, year of death, and year of birth for women and men separately to estimate population exposures and mortality. The KTDB was created using a uniform methodology for all countries, and the reliability of these data is stringently assessed on an ongoing basis. Hence, KTDB data are of higher quality than most countries' official estimates, and they permit international comparisons.

A single article cannot cover all aspects of old-age mortality trends in all countries included in the KTDB. Our primary focus here was on countries with lowest mortality. Other interesting developments, such as the far-reaching changes in Central Europe, have only been slightly touched upon. Unfavorable developments in the countries of the former Soviet Union were outside the scope of this article.

We have shown that the increase in the number of octogenarians and nonagenarians has continued since Kannisto's publications more than ten years ago. In the last year of our overview (2004), the number of women and men aged 80–99 in the KTDB countries was 37 million, a 33 percent increase since 1990. The number of centenarians has grown even faster in recent years: about 60,000 recorded in 1990, almost 130,000 in 2004—an increase of more than 100 percent in 14 years. The rapid growth in the number of centenarians is mainly the result of two processes. First, because of survival improvements among people below age 100, more people are able to reach that age. Second, mortality at ages 100 and higher is decreasing—a rather recent phenomenon, shown by Kannisto (1993, 1994, 1996) and Vallin and Meslé (2001).

Of course, an increase in the number of centenarians is possible without any mortality reductions; it may simply occur as larger birth cohorts reach the highest ages. Vaupel and Jeune (1995) show, however, that increases in births are relatively unimportant. Our subsequent analyses of survival probabilities and life expectancy provide evidence that improvements in survival among the oldest-old are indeed the cause of the growing numbers of elderly: on average, the probability of surviving from age 80 until age 90 approximately doubled between 1950 and 2002 (1950: 12 percent; 2002: 25 percent) among men, and rose from 16 percent to 38 percent among women. Japan, which in 2002 had the highest survival rates from ages 80 to 90 for women and men, and from ages 90 to 100 for women, was also recently the leading country in life expectancy at age 80 (8.15 years for men and 10.81 for women in 2000).

The dynamics of mortality change have been analyzed using Lexis maps of average annual declines in age-specific death rates. The most impressive improvements were found among Japanese women. In recent years, mortality in Japan has been dropping at almost all ages between 80 and 99 at a pace of 3 percent annually. Researchers did not foresee this trend, and projected a convergence of Japanese mortality decline toward international trends (Wilmoth 1998).[3] Although to a lesser extent than Japan, countries like France and Italy have experienced remarkable improvements among the oldest-old as well. Another success story is the former East Germany. While Japan's mortality improvements appear to be initiated by a cohort-like pattern, the manner in which eastern Germany caught up to the western part after reunification reflects a clear period pattern.

These improvements are not universal among developed countries. Besides Denmark, the Netherlands, and, to some extent, Norway, the United States is probably the most prominent exception. The United States was the lead country in old-age mortality decline for decades (Manton and Vaupel 1995) but has fallen well behind during the last 15 years. Survival improvements have been at best modest since the 1980s and completely absent for women since the late 1990s. Although research is ongoing, we believe that the root causes for these unwelcome developments are not insurmountable mortality thresholds. For Denmark, for example, it has been convincingly shown that the slow increase in life expectancy among women can be attributed to the smoking behavior of cohorts of women born between the two world wars (e.g., Jacobsen et al. 2002). In the Netherlands, in addition to comparatively modest improvements in cardiovascular mortality (Janssen et al. 2004, 2007), early-life factors such as "unfavourable socio-economic developments between 1895 and 1915" (Janssen et al. 2007: 184) and a "combination of growing frailty of the Dutch elderly population together with changes in the medical and social services available to them" (Janssen et al. 2003: 733) are thought to be the causes of the stagnation in mortality decline (Nusselder and Mackenbach 2000).

While improvements in data quality can be a contributing factor to the slow improvements in survival observed in the United States, Meslé and Vallin (2006: 136) argue that "the comparison between the United States or the Netherlands and Japan or France clearly supports the notion of a third stage of the health transition centered on the aging process." Whereas the four countries have successfully passed through the first two stages of the health transition—Omran's epidemiologic transition and the "cardiovascular revolution" (e.g., Vallin and Meslé 2004)—only Japan and France appear to have been able to take the next step. These two countries have seen substantial reductions in mortality at the oldest ages, not only from heart disease, but also from other causes of death, such as cerebrovascular disease, infectious and respiratory diseases, and mental disorders.

As an interesting aside, the *Guardian* newspaper reported on 28 April 2007 that bookmakers in Britain are adjusting their offers to take bets on survival to age 100 for 90-year-olds: "[B]ookmaker William Hill announced it will no longer be offering such generous odds to those backing themselves to live to 100. Alec Holden from Epsom, Surrey, picked up a £25,000 cheque from William Hill this week after he celebrated his 100th birthday. After making its third such pay-out in less than 18 months, William Hill has said it is now raising the target age for such wagers to 105, and even 110."[4]

Studying mortality developments among the oldest members of society can help to shed light on the question "How much can human life span be extended?" This, according to *Science* magazine, is one of the "scientific puzzles that are driving basic scientific research" (Couzin 2005; Kennedy and Norman 2005).[5] Although several countries were not able to decrease mortality during the last ten years at a pace as fast as that achieved in the previous decade, many other countries have done so. If biological and practical boundaries are looming, we would expect that the populations with the lowest mortality levels should show a deceleration in survival improvements. Evidence for mortality among women in today's lowest-mortality countries—Japan and France—suggests otherwise.

Notes

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1 Following the methodology outlined in Vaupel (1986), we estimated that gains in survival at age 86 provided the largest potential for increasing life expectancy for Japanese women in 2004.

2 To obtain comparable estimates, the average annual rate of improvement in mortality has been calculated in the same way as given in endnote 3 of Kannisto et al. (1994). The basic building blocks are age- and period-specific death rates $m(x,y)$:

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

where the numerator $D(x,y)$ denotes the number of deaths at age x in year y, and the denominator estimates the mean population at the same age and time. When death rates were required for age and time intervals, the average death rates for the time interval y through y^* and age interval x through x^* were calculated as:

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

where *w(i)* is a weight for age standardization to obtain comparable estimates across countries and time periods. The weights have been calculated as the age-specific contributions of the combined female and male Swedish population aged 80 to 104 for the time period 1950 through 1990. Based on $\overline{m}$, the average annual rate of improvement ρ has been calculated as:

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

where δ denotes the interval between the means of the latter period (subscript 2) and the earlier period (subscript 1).

3 It should be noted, however, that Wilmoth's 1998 article addressed life expectancy at birth.

4 The article is located at «http://money.guardian.co.uk/personalpensions/story/0,,2067087,00.html» and was accessed on 14 May 2007.

5 Out of 125 questions pointing to critical knowledge gaps, *Science* selected 25 based on how "fundamental they are, how broad-ranging, and whether their solutions will impact other scientific disciplines" (Kennedy and Norman 2005: 75). Among those 25, "How much can human life span be extended?" was listed as the sixth question.

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