Emergence of supercentenarians in low mortality countries

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Abstract

Although the exponential increase in the number of centenarians which started just after World War II is today well documented in Europe and Japan, this is still not the case for extremely old persons having reached the age of 105 years -the semi supercentenarians- or even of 110 years -the supercentenarians-. The first cases of validated supercentenarians appeared in the 1960s but their numbers have steadily increased since the mid 1980s, The current prevalence of known super-centenarians in low mortality countries involved in the International Database on Longevity (IDL) is approximately 10 times more than in the mid 1970s. In roughly twenty years, from 1980 to 2000, the maximum reported age at death, assumed to indicate the maximum life span of the human species and itself seen as a quite stable characteristic of our species, has increased by about 10 years from 112 to 122 years. The annual probability of death at age 110 is as low as 0.52 and stagnates after that age (0.50) when using only data from countries with valid and complete data on supercentenarians (9 countries and 159 validated observations). All the computed probabilities between ages 110 and 115 years fall far below a ceiling of 0.6 a value previously proposed by other researchers. Our results strongly support the finding that mortality does NOT increase according to the Gompertz curve at the highest ages and the results are consistent with a plateau around age 110-115. The data after age 115 are so sparse that they are not analysed here, but an earlier study, suggests that mortality may fall after age 115. We intend to analyse this question in subsequent research.

Beyond the age of 100 years death rates fall far below the Gompertz trajectory fitted on mortality rates before the age of 85 years. Alternative trajectories have been proposed to take into consideration the mortality deceleration observed after the age of 85 years in low mortality countries. Some authors have suggested a trajectory tending but never reaching a plateau or a ceiling of mortality (Thatcher et al., 1998; Thatcher, 1999b; Lynch and Brown, 2001) whereas others have suggested that the mortality rates could decline after having reached a maximum (Vaupel et al., 1998). Even if limits still remain in practice (Olshansky et al, 2001), such trajectories will have substantial impact on the ages and the number of extremely old people in the future as well as having theoretical implications. It is therefore important to test these new models with empirical data among the oldest old. Between the ages of 90 and 100 years the three proposed trajectories are not sufficiently different from each other to allow this empirical verification. However, above the age of 110 proposed logistic and quadratic trajectories are clearly distinct from the Gompertz and above the age of 115 they become clearly distinct each from the other but empirical data above the age of 115 are still extremely sparse. Thus the current emergence of supercentenarians (Robine and Vaupel, 2001) allows a testing of these new trajectories by empirical data between 25 and 30 years after the assumed point of inflexion of about 85 years. This paper is a first attempt to assess which group of trajectories is confirmed by empirical data between the age of 110 and 115 years when the exponential trajectories on the one hand and the logistic or quadratic trajectories on the other hand have diverged sufficiently.

1. The data

After a feasibility study during the year 2000 (Robine and Vaupel, 2001), it was decided to establish the International Database on Longevity (IDL) at the University of Montpellier 1 as an international collaborative effort of researchers interested in extreme human longevity by gathering validated demographic data on supercentenarians defined as individuals having reached the age of 110 years.[1] The IDL database, still in development, will be directed by a Consortium to be established by three leading research institutions.[2] The provisional Scientific Committee is assisted by an Advisory Board gathering representatives of almost all demographic research centres in low mortality countries. The database aims to contain

[1] More information on the Database are available at http://www.supercentenarians.org

[2] The National Institute on Health and Medical Research, INSERM (France), the National Institute for Demographic Studies, INED (France) and the Max Plank Institute for Demographic Research, MPIDR (Germany) .

complete and validated lists of supercentenarians, arranged by nationality at birth. These lists will include supercentenarians who are alive as well as those who have died. For each supercentenarian, the database will include an anonymous case number, information on his/her date of birth, date of death (if known), sex, on the methods used to validate the person's age, and how the person was ascertained. In September 2001 the database contained 191 validated records including 179 records corresponding to 9 countries with valid and complete data: Belgium, Denmark, England and Wales, Finland, France, Japan, the Netherlands, Norway, and Sweden.

The IDL database is complemented by an international list of supercentenarians gathered on the internet by Louis Epstein with the help of Robert Young (http://www.grg.org). Taken together, both databases contained 258 cases in September 2001 (Table 1). List 1 corresponds to the merging of the IDL data with the list of the Los Angeles Gerontology Research Group (Louis Epstein's list) with exclusion of cases born before 1850, such as the case of Pierre Joubert (except G A Boomgaard and H K Pluncket) and of the case of S Izumi. List 2 corresponds to the IDL data, that is the list of cases provided by the national informants of the IDL. For all cases, the informants of the IDL must provide copies of the birth records (This list excludes E Morris, from England and Wales, who died in 2000, A Akafi from Finland, and Smith-Johnnasen, Norway/The Netherlands, and includes Sarah DeRemer Knauss from the United States). List 3 is limited to the 9 countries with valid and complete data where complete means that a country has the necessary mechanisms to ensure that almost all supercentenarians can be identified. Therefore this list excludes 12 validated cases from Australia (1), Canada (8), Ireland (1), Italy (1) and the United States (1).

Table 1: Number of validated cases of supercentenarians according to the International Database on Longevity (IDL) and to the List of Supercentenarians of the Los Angeles Gerontology Research Group by list in September 2001

	List 1 (n=258)*	List 2 (n=191)**	List 3 (n=179)***
110	97	85	82
111	52	41	38
112	32	23	22
113	15	8	7
114	12	5	5
115	7	4	4
116	2		
117	2	1	
118			
119	1	1	
120			
121			
122	1	1	1
Dead	221	169	159
Alive	37	22	20
Total	258	191	179

*List 1 corresponds to the merging of the IDL data with the List of the Los Angeles Gerontology Research Group (Louis Epstein's list) with exclusion of cases born before 1850, such as the case of Pierre Joubert (except G A Boomgaard and H K Pluncket) and of the case of S Izumi; **List 2 corresponds to the IDL data, that is the list of cases provided by the national informants of the IDL (the list excludes E Morris from England and Wales, dead in 2000, A Akafi from Finland, Smith-Johnnasen from Norvay/The Netherlands, and includes Sarah DeRemer Knauss from the United States). For all cases, the informants of the IDL must provide copies of the birth records; ***List 3 includes only valid and complete IDL lists: Belgium, Denmark, England and Wales, Finland, France, Japan, Netherlands, Norway, and Sweden (excludes Australia, Canada, Ireland, Italy and the United States).

Case validation is extremely important for these exceptional individuals (Jeune et al., 1999). Most of the data used in this analysis have been carefully validated, especially those concerning the oldest old who have reached the age of 115 years or more (Laslett, 1994; Wilmoth et al., 1996; Robine and Allard, 1998; Desjardins, 1999). Thus from the records collected by the international list, we have excluded individuals allegedly born before 1850 with poor evidence of the date of birth (less than one dozen of cases). We have also excluded 8 individuals acknowledged as false cases, such as the famous Canadian, Pierre Joubert, born in 1701 (Charbonneau, 1990), or with incomplete data, such as the Japanese man, Shigechiyo Izumi, born in 1865 and judged to be a false case by the Japanese scholars (letter to Jacques Vallin). This leaves a total of 258 records with the minimal requirements of the list of the Los Angeles Gerontology Research Group (known date of birth and date of death). Table 2 shows the distribution of these supercentenarians according to their country of birth and also indicates the maximum age reached in each country.

Adding up the numbers of supercentenarians in the 9 countries with valid and complete data and dividing the total by the total population in these countries in 2001, we have computed a crude ratio of 0.6 supercentenarian per million inhabitants in the combined population of the 9 countries with valid and complete data. Table 2 also shows an estimate of the expected cumulative number of known supercentenarians (dead and alive) in each country, calculated by multiplying this crude ratio by the current population in each country (mid-2001, Population Reference Bureau, Pison 2001). These calculations give a crude estimation of the degree of completeness of the data for the countries with incomplete data (see Table 2). Among the list of countries with valid and complete data, Japan has less cases than expected, explained by the fact that the Japanese list did not start until 1996. This deficit of Japanese cases lowers the current ratio of supercentenarian per million inhabitants and explains why France, England and the Netherlands on the other hand have more cases than expected. However, using this somewhat conservative ratio, permits estimation of the number of expected supercentenarians in countries known to have incomplete data.

Table 2: Number of validated cases of supercentenarians according to the International Database on Longevity (IDL) and to the List of Supercentenarians of the Los Angeles Gerontology Research Group by country of birth (List 1, n=258 in September 2001)

Country	Observed number	Expected Number*	Maximum Age Reported
Valid and complete data**			
Belgium	6	6	111
Denmark	3	3	115
England & W	46	36	115
France	50	36	122
Finland	2	3	112
Japan	45	77	114
Netherlands	16	10	113
Norway	5	3	112
Sweden	6	5	112
Subtotal	179	179	122
Incomplete data***			
Australia	4	12	112
Canada	8	19	117
Germany	1	50	…
Greece	1	7	122
England &W	2	-	115
Ireland	1	2	111
Italy	6	35	112
Japan	7	-	116
Poland	1	23	112
Rep Tche	1	6	…
Roumania	1	14	115
Russia	1	87	…
S. Africa	1	26	111
Spain	5	24	113
Other UK	5	-	113
Ukrania	1	30	…
United States	31	172	119
Subtotal	79	507	119
Total	258	686	122

*Expected number calculated with the crude ratio of 0.6 supercentenarian per million inabitants.
**Belgium, from 1960; Denmark, from 1960; England & Wales, 1960-1999; France, from 1960 + Insee 1987-2000; Finland, from 1960; Japan, 1996-2001; Netherlands from 1960 (Geert Adriaans Boomgaard 21/09/1788-03/02/1899); Norway, from 1960; Sweden, from 1960.
***England &Wales, after 2000; Japan, before 1996; Other UK, other than E&W.

Table 3 compares the life spans of supercentenarains from countries with valid and complete data to those of supercentenarians from countries with incomplete data. In the former countries, the number of people having lived to age 110 years is more than the number of people having reached the 111-114 age group and the number of people having reached the age of 115 years or more is extremely low (3%). By contrast, in the latter countries the number of people having lived 110 years is low (24%) and the number of people having reached the age of 115 years or more high (13%). The life-span structure of supercentenarians from countries with valid and complete data is much more coherent with what we know about the age structure of the human population and its survival curve (Kannisto, 1993). The life-span structure of supercentenarians from countries with incomplete data suggests two issues. Firstly there appears to be a deficit of "young" supercentenarians due to incompleteness, the likelihood of being known increasing with age. Secondly there is an excess of "oldest-old" supercentenarians due to age inaccuracy, a significant part of the data collected by the Los Angeles Gerontology Research Group being poorly validated.[3]

Table 3: Life spans of the supercentenarians from countries with valid and complete data (International Database on Longevity, IDL list3) and from countries with incomplete data (International Database on Longevity, IDL list 2, and List of the Los Angeles Gerontology Research Group by country of birth, (=list 1 – IDL list 3), excluding living supercentenarians (September 2001)

	List 3*	List 1** - list 3*	Total
Number			
110	82	15	97
111-114	72	39	111
115 +	5	8	13
Total	159	62	221
Percentage			
110	51.6	24.2	43.9
111-114	45.3	62.9	50.2
115+	3.1	12.9	5.9
Total	100.0	100.0	100.0

*List 3 Valid and complete IDL lists: Belgium, Denmark, England and Wales, Finland, France, Japan, Netherlands, Norway, and Sweden (excludes Australia, Canada, Ireland, Italy and the United States); **List 1 corresponds to the merging of the IDL data with the list of the Los Angeles Gerontology Research Group (Louis Epstein's list) with exclusion of cases born before 1850, such as the case of Pierre Joubert (except G A Boomgaard and H K Pluncket) and of the case of S Izumi.

[3] Looking only at the data gathered by the Los Angeles Gerontology Research Group which are not validated by ARLES informants and then not included in the International Database on Longevity (IDL), shows an even more distorted life spans structure.

Age inaccuracy in countries with incomplete data appears stronger for males (data not shown). Table 4 shows the sex-ratio among supercentenarians, limited to countries with valid and complete data. Even here the number of male supercentenarians is so low that behind the mean ratio of 1 male to 8 females for the 9 countries with valid and complete data, the ratios vary from 1:20 in England & Wales to 1:4 in Japan.

Table 4: Sex-ratio among the supercentenarians from countries with complete and valid data (International Database on Longevity, IDL list3, September 2001)

	Females	Males	Total	Sex-ratio
England & Wales	44	2	46	1/21
France	45	5	50	1/9
Japan	36	9	45	1/4
Other countries	34	4	38	1/8.5
Total	159	20	179	1/8

List 3 Valid and complete IDL lists: Belgium, Denmark, England and Wales, Finland, France, Japan, Netherlands, Norway, and Sweden (excludes Australia, Canada, Ireland, Italy and the United States)

In summary, the data used in this analysis come from 25 countries although the degree of completeness varies considerably from one country to another. Thus among the 258 records gathered in September 2001, 191 come from the 14 countries currently associated in the International Database on Longevity (IDL), with 9 countries providing 75% of the cases. In the analysis following, extreme caution is taken when using the data of the Los Angeles Gerontology Research Group not validated by ARLES informants.

2. The emergence of the supercentenarians

The dynamics of the supercentenarian population and its size at the end of each interval (the prevalence) depend on two components, the interval incidence of the 110th birthday and the deaths of supercentenarians during the interval. The series displayed on subsequent figures have been stopped at the year 1999 because the validation process for the deaths of 2000 is not yet completed for England & Wales, one of the three large countries with valid and complete data. Most supercentenarians are only identified at the time of their death through obituaries or death records when provided by national authorities (England & Wales, France, Japan or Sweden). Often only the oldest living supercentenarian is known in each country and they are often the subject of articles in newspapers at the time of their birthday. He or she is in general the one recorded by the *Guinness Book of Records* although this is not always the case. Therefore the incidence and the prevalence are slightly underestimated for the most recent years, especially for the final year corresponding to the youngest supercentenarians.

Figure 1: Emergence of supercentenarians: incidence of new cases since 1950 (crude numbers)

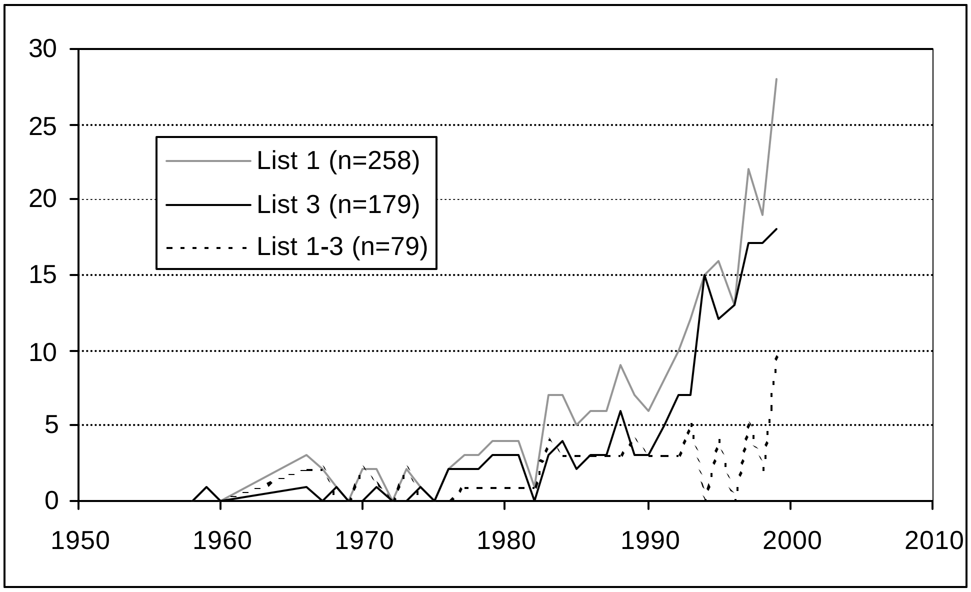

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Figure 1 shows the emergence of supercentenarians in the 1960s with the first validated cases. These new cases during the sixties and seventies are exceptional, one or two cases maximum by year and not each year. The curve corresponding to the countries with valid and complete data (list 3) shows an exponential increase in the emergence of new cases from the mid 1970s. By contrast the complementary list of incomplete data (list 1-3) shows larger fluctuations behind a more linear increase. Again age inaccuracy for the earlier cases and incompleteness for the most recent years could explain this linear tendency. The shape of the total curve (list 1) is a combination of these two tendencies. Before 1960, only three cases were in the International Database on Longevity (IDL): a Dutch man, Geert Adrians Boomgaard, born in 1788 who appears to have reached the age of 110 years in 1898[4], an Irish woman, Katherine Plunket, born in 1820 who reached the age of 110 years in 1930 (Thatcher, 1999a), and a Dutch woman, Christina Back-Karmebeek, born in 1849, who reached the age of 110 years in

[4] Some data on Geert Adrians Boomgaard are provided by Heeres (1976). Dany Chambre and Gert Jan Kuiper have collected his first marriage record (04/03/1818) and his death record (03/02/1899) with many genealogical data on his ancestors on six generations. Several photos and press cuttings on Geert Adrians Boomgaard are available.

1959, corresponding to the first case on Figure 1. More than fifteen new cases in the 9 countries with valid and complete data became known to IDL in 1999.

Figure 2: Deaths of supercentenarians reported since 1950 (crude numbers)

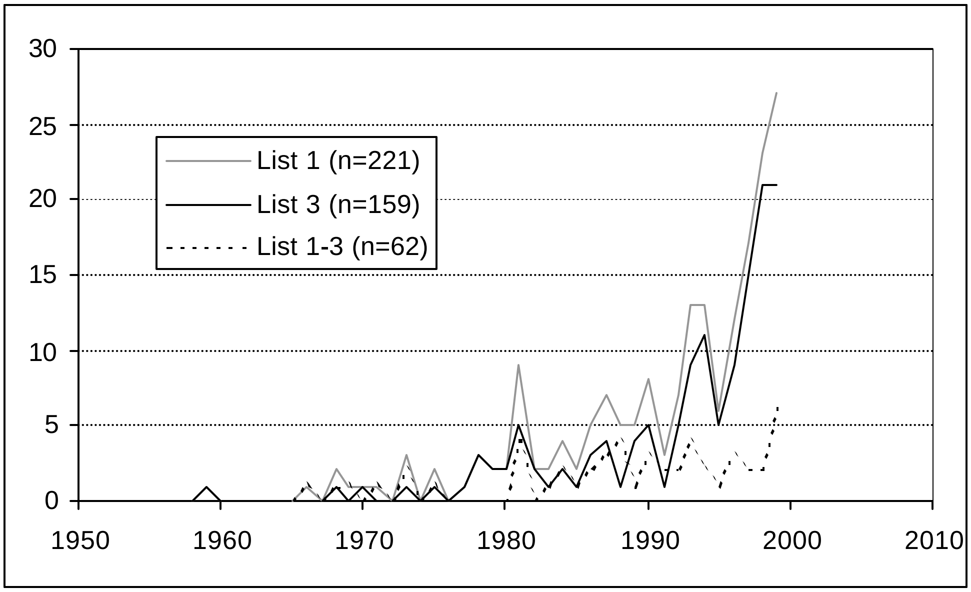

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Figure 2 shows the number of deaths of supercentenarians since the 1950s and confirms the two tendencies observed, exponential increase when taking into account only the countries with valid and complete data and linear increase when looking only at the countries with incomplete data. In 1998 and in 1999 more than twenty deaths of supercentenarians were reported in the 9 countries with valid and complete data.

Figure 3: Prevalence of supercentenarians since 1950 (crude numbers)

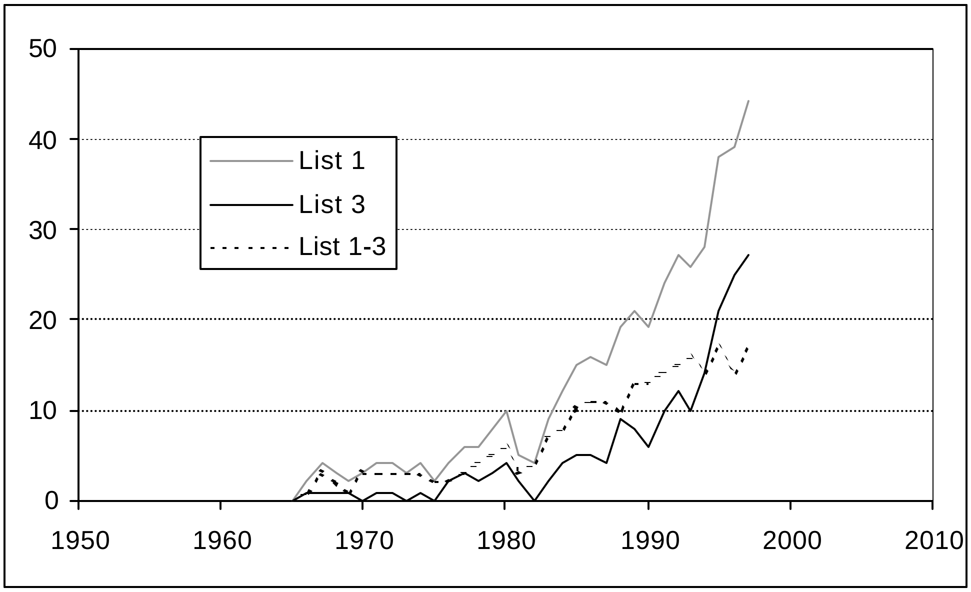

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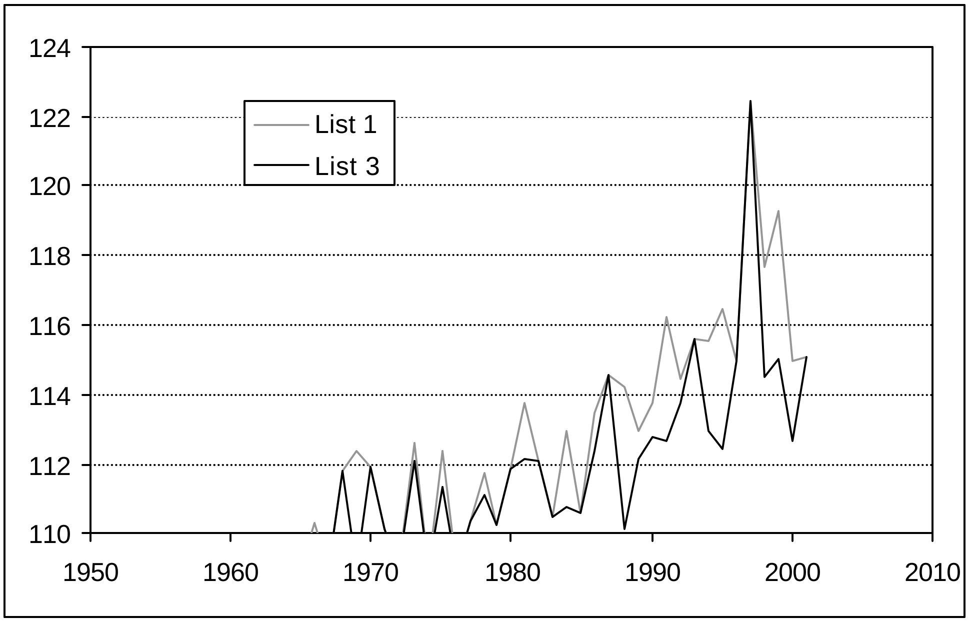
Figure 3 shows the prevalence of living supercentenarians at the end of each year since 1950. One has to wait until the mid 1960s to observe a living supercentenarian at the end of the year. Since that period several years have ended without any living supercentenarians, for instance 1982 for the 9 countries with valid and complete data. Sixteen years later more than 25 supercentenarians where alive in these countries at the end of 1998. Here also the increase is exponential whereas it is only linear when looking at countries with incomplete data. Obviously many existing supercentenarians have yet to be found in the low mortality countries with incomplete data, such as Australia, Canada, Germany, Italy, Spain or the United States.

3. The maximum age at death observed

Figure 4 shows a huge increase in the maximum reported age at death registered each year since the beginning of the 1980s. In roughly twenty years the maximum reported age at death registered has increased by about 10 years from 112 to 122 years.

Figure 4: Maximum Reported Aged at death registered since 1960



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Even if we exclude the case of Jeanne Calment, dead at the age of 122 years in 1997 as an outlier, the increase is still very strong, with the case of Marie Louise Meilleur from Canada, dead at the age of 117 years in 1998 and the case of Sarah Knauss[5] from the United States, dead at the age of 119 years in 1999. In total since 1993, eight cases of people reaching their 115th birthday have been meticulously validated (Robine, 2001b). Until now, according to most biologists the maximum human life span has been a biological constant of about 100-

[5] The case of Sarah Knauss provides a good example of validation in the absence of a birth record. Sarah De Reemer Clark Knauss was born Setember 24th, 1880 in the village of Hollywood, Hazle township, Luzerne County, Pennsylvania. We don't have any birth documentation for her but she was recorded on June 5th, 1900 in the Twelfth Census of the United States as Sadie, daughter, born Sept 1880, age 19, single living with: Clark Walter, Head, born April 1849, age 51, married since 25 years; Amelia, Wife, born June 1857, age 42, married since 25 years, having 7 children, 4 living; Charles, son, born July 1878, age 21, single; Sadie…; Earl, son, born May 1889, age 11, single; and Emily, daughter, born May 1893, age 7, single. Walter Clark was recorded in the 1880 Federal Census of Holliwood village with his family: Walter Clark, age 31, engineer; wife Emelia, age 23, keeping house; son albert L, age 4; and son Charles H age 2. The age correspondance between the two census is right for Walter Clark, Amelia and Charles. Sarah was born the following September 24th, 1880. Sarah De Reemer Clark and Abraham Lincoln Knauss were married by Rev. Dr Gilbert Henry Sterling on August 28th, 1901 (Application for marriage license, Sarah DE R. Clark, 21 years; Marriage record Cathedral Church of the Nativity Bethlehem, Sarah Deremer Clark, age 20; The GLOBE, South Bethlehem, Thursday, August 29th, 1901: '…of the contracting couple, Abraham Lincoln Knauss and Miss Sadie De Reemer Clark'). Thus there is no doubt that a daughter of Walter and Amelia Clark, born in September 1880 and named Sarah (Sadie) De Reemer, was 19 years old in September 1900 (Twelfth US Census) and 20 years old (Close to 21 years old) when she married Abraham Lincoln Knauss on August 1901. There is no reason to consider that this person is other than Sarah Clark Knauss who was resident of the Phobe Home in Allentown, Pennsylvania, known to be 118 years old when we have visited her in November 1998. Since her marriage her family history is well documented. This case was documented by Edith Rodgers Mayer (Phoebe Ministries, 1997).

110 years for *homo sapiens* for about 100,000 years (Cutler, 1985; Walford, 1985). Our study shows that during the last 20 years only, from 1980 to 2000, this constant appeared to have increased by 10 years, i.e. about 10% of the alleged value for the human span, challenging all our previous knowledge on the potential life span of the human species. A recent analysis of the world trend in maximum life span over two centuries confirmed our analysis (Wilmoth and Robine, Submitted).

4. The mortality rates

Table 5 shows that the annual probability of death at age 110 is as low as 0.516 for the countries with valid and complete data (list 3, n=159). By contrast the probability of death at age 110 is only around half of this level when using only the data coming from countries with incomplete data (list 1-3, n=62), consistent with our doubts as to the quality of the incomplete data. The annual probability of death with the full sample (list 1, n=221) is a combination of these two values. Due to small numbers at the highest ages, on table 5, we give the annual values only between age 110 and 114 years and summarize the data contrasting the annual probability of death at age 110 to the annual probability of death at age 111 and above.

All the computed probabilities fall below the ceiling of 0.6 proposed by Kannisto in 1999[6]. The probabilities of death appear to stagnate between 110 and 114 years when using only the data coming from the 9 countries with valid and complete data (Figure 5). By contrast the probabilities of death increase between 110 and 114 years when using only the data coming from countries with incomplete data but the death rates at 110, 111 or 112 years appear much too low.

[6] The quotient of mortality or the probability of dying within 12 months is also the same as the quantity given as q_x in life tables.

Table 5: Annual probability of death at age 110 and beyond

	List 1 (n=221)	List 3 (n=159)	List 1 - List 3 (n= 62)
110	0.439	0.516	0.242
111	0.419	0.494	0.298
112	0.444	0.564	0.303
113	0.375	0.412	0.348
114	0.480	0.500	0.467
115+	0.433	0.417	0.444
110	0.439	0.516	0.242
111+	0.426	0.497	0.346

List 1 corresponds to the merging of the IDL data with the list of the Los Angeles Gerontology Research Group (Louis Epstein's list) with exclusion of cases born before 1850, such as the case of Pierre Joubert (except G A Boomgaard and H K Pluncket) and of the case of S Izumi; List 3 Valid and complete IDL lists: Belgium, Denmark, England and Wales, Finland, France, Japan, Netherlands, Norway, and Sweden (excludes Australia, Canada, Ireland, Italy and the United States).

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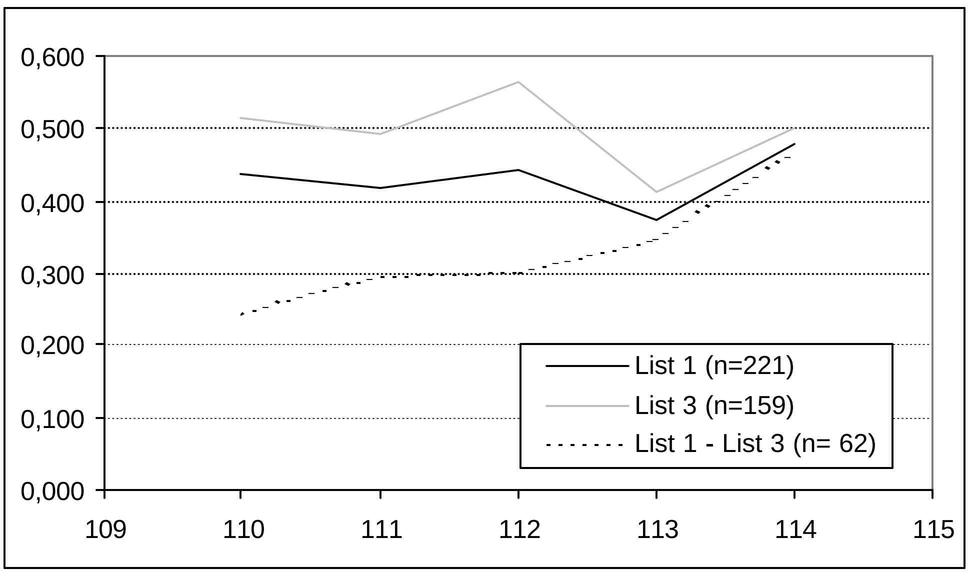

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Vincent advocated that the quotients of mortality at very high ages should be calculated by the method of extinct generations (Vincent, 1951). It was impossible to apply this method in our analysis because one of our hypotheses was precisely that there is no natural limit in terms of age to consider that a human generation is extinct. However from a practical point of view, most of the supercentenarians included in this analysis were born after 1878 and belong to non extinct generations if we consider the age at death of Jeanne Calment of 122 years as the current empirical age limit. In the 9 countries with valid and complete mortality data, the discovery at the time of their death of new cases belonging to these generations and still living today will decrease the mortality rate at age 110 in comparison with the rates beyond that age. However we can improve the accuracy of the death rate after the age of 111 years, at the last age group, if we compute a global rate corresponding to a central death rate above the age of 111 years. The numerator is the number of deaths above the 111th birthday and the denominator is the total person-years of exposure (i.e., person-years lived) above this age. These values again confirm the conclusion reached from Figure and Table 5 (Table 6). [7]

Table 6: Central death rate at age 110 and beyond

	List 1 (n=221)	List 3 (n=159)
110+	0.573	0.721
110	0.598	0.752
111+	0.554	0.692

List 1 corresponds to the merging of the IDL data with the list of the Los Angeles Gerontology Research Group (Louis Epstein's list) with exclusion of cases born before 1850, such as the case of Pierre Joubert (except G A Boomgaard and H K Pluncket) and of the case of S Izumi; List 3 Valid and complete IDL lists: Belgium, Denmark, England and Wales, Finland, France, Japan, Netherlands, Norway, and Sweden (excludes Australia, Canada, Ireland, Italy and the United States).

5. Discussion

Overall these results confirm our initial worries about the effect of the lack of complete data on the calculated rate. When the data are incomplete (List 1-3), it is possible that the older the supercentenarian the greater his chance of being known, leading to an underestimation of the shortest life spans, corresponding to the supercentenarians ending their life in the first place soon after the age 110 years, and consequently to an underestimation of the death rate at 110, 111 or 112 years compared to the death rate at 114 or 115 years of age.

The valid and complete series show no trend in the death rate beyond the age of 110 years, suggesting that a plateau of mortality has been reached. In comparison, the French life table of 1995-1997, both sexes together, shows that on average between the age of 80 and 85 years, the probability of death increases by 1.12 (12%) with each additional year of age (Beaumel et al., 1999).

All the computed probabilities between ages 110 and 115 years fall far below a ceiling of 0.6, confirming a previous analysis with the first collected data (Robine and Vaupel, 2001). Our

[7] As expected the central death rates are much higher than the quotients of mortality, the probabilities of dying within 12 months at each birthday.

results strongly support the finding that mortality does NOT increase according to the Gompertz curve at the highest ages and the results are consistent with a plateau around age 110-115. The data after age 115 are so sparse that they are not analysed here, but an earlier study, based on less complete data (Vaupel et al. 1998), suggests that mortality may fall after age 115. We intend to analyse this question in subsequent research.

Supercentenarians first emerged consistently in the 1960s and their numbers have been expanding dramatically since. Our conclusion that alternative models fit better the mortality experience at extremes ages than the Gompertz curve will mean larger numbers of supercentenarians in the future. In addition large fluctuations has been observed in the distribution of deaths among supercentenarians according to seasons of the year, demonstrating perhaps their frailty (Robine and Vaupel, 2001). This suggests that there is not only a need to build on the new concept of plasticity of longevity, which describes how modifications in environment may result in large changes in lifespan but that we also need a model which explains how the new mortality trajectories can take into account the protected environment in which we place our frail older people (Robine, 2001a).

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