THE GERONTOLOGICAL SOCIETY OF AMERICA®

Journals of Gerontology: Social Sciences
cite as: *J Gerontol B Psychol Sci Soc Sci*, 2018, Vol. 00, No. 00, 1–10
doi:10.1093/geronb/gby033
Advance Access publication March 26, 2018

OXFORD

Research Article

Beyond One Hundred: A Cohort Analysis of Italian Centenarians and Semisupercentenarians

Graziella Caselli, PhD,[1] Marco Battaglini, MS,[2] and Giorgia Capacci, MS[2]

[1]Department of Statistics, Sapienza University of Rome, Italy. [2]Italian National Institute of Statistics, Directorate for Social Statistics and Population Census, Rome, Italy.

Address correspondence to: Graziella Caselli, Department of Statistics, Sapienza University of Rome, viale Regina Elena 295, Rome 00161, Italy. E-mail: graziella.caselli@uniroma1.it

Received: November 20, 2017; Editorial Decision Date: March 5, 2018

Decision Editor: Deborah Carr, PhD

Abstract

Although the increase in the number of centenarians is well documented today in countries with advanced demographic data, the same is not true for those aged 105 years and over. The first aim of this paper was to analyze the demographic characteristics of the 4,626 validated semisuper and 102 supercentenarians for the cohorts born between 1896 and 1910, referring to Italian Semi-Supercentenarians Survey. Then, starting from this data and from the survival histories in old ages—reconstructed by Vincent's *Extinct - Cohort Method*—for the cohorts born between 1870 and 1904, the most important aim was to analyze longevity history and the trend of gender gap of the Italian oldest cohorts beyond 100 years old. The Italian centenarians and semisupercentenarians increase from the first to the last cohort is due to the survival rise in old ages and the increase in the gender gap at extreme ages depends on the higher survival of women than men after 60 years old. Around 110–112 for both genders (for women in particular) a kind of resistance to further progress seems to appear in our analysis as in more recent studies on supercentenarians.

Keywords: Cohort life tables, Longevity, Oldest old, Survey

Introduction

During the second half of the 20th century and particularly after 1970, the progress in the socioeconomic and medical-health spheres, together with changes in individual and group life-styles, all ensured major gains in life expectancy. A child born today in Italy may expect to live until age 85 years if it is a girl and almost 81 years (80.6) if it is a boy. This places Italy in one of the first positions in Europe (for Spanish women the figure is 85.8 years and for Sweden men 80.6 years. Period life table 2016: Istat 2017; Ined, 2017; Ine, 2017). Forty-six years ago life expectancy at birth was about 75 and 69 years for women and men, respectively, meaning there has been an average gain of 10 years for women and 12 for men. What we are witnessing is a real revolution, made possible by major gains in life expectancy among the elderly adults. In the same period, women and men over 65 years old have added 6 years to their average life span (from 16 to 22 years for women and from 13 to 19 years for men). Those over the age of 80 gained 3.5 (from 6.8 to 10.3 years) and 3 years (from 5.5 to 8.5 years), the figures being for women and men, respectively.

According to the most recently available Italian life tables, 75% of women and 62% of men are expected to be alive at 80 years. This means that more than 69% of the population die after their 80th birthday. For women, it should be noted, 30% of these deaths take place after they have reached 90 years of age (only 23% for men). The number of people still alive between 90 and 100 years has also increased over time (almost 30% today as against 8%

in 1970), while, of course, the mortality curve is continually moved forward in favor of older ages (Caselli, Vaupel, & Yashin, 2006a). A brief examination of mortality data provided by the National Institute of Statistics, shows not only that the total number of deaths after 100 has more than doubled (4,200–8,200) between 2006 and 2016, with a constant number of births for the cohorts of origin (Figure 1) but also that the numbers of those dying after 105 years is growing all the time at a higher rate of increase than that for preceding age groups (100–104 years).

Thus, people have less chance of dying during young and adult ages, meaning that more and more people reach old age and, once the old-age threshold is crossed, death occurs later (Kannisto, 1994); a trend that arouses a certain amount of concern given its unprecedented impact on the increase in the number of the elderly adults and on the welfare expenditure due to population ageing. In Italy, for example, the over 65-year-old population has now outpaced the under-15 population (2017: 22.3% compared with 13.5%), the number of the oldest old (80 years and over) is growing all the time (from 1 million in 1970 to 4.1 million today, 1.7% and 6.8%, respectively of the total population), and the number of living centenarians has doubled in the last 12 years (from about 9,000 in 2005 to 18,000 in 2017).

As we all know, ageing, both absolute and relative, involves considerable social and individual costs, causing difficulties for the welfare state, the family system and intergenerational relationships. Nor should we overlook the fact that the older a person is, the more he will have to grapple with late-onset diseases. Ageing and longevity are very topical questions on today's agenda. New statistical data on the oldest old and on mortality up to extreme ages, over time and by cohort, are able to reveal the time and age pattern of survival improvements, and to provide important elements for analysis aimed at better understanding some aspects of human longevity. For this last reason, in the most developed countries in the world, as in Italy, in the last two decades, great attention has been paid to collecting data on centenarians and semisupercentenarians, and to studying the characteristics of their survival after this age.

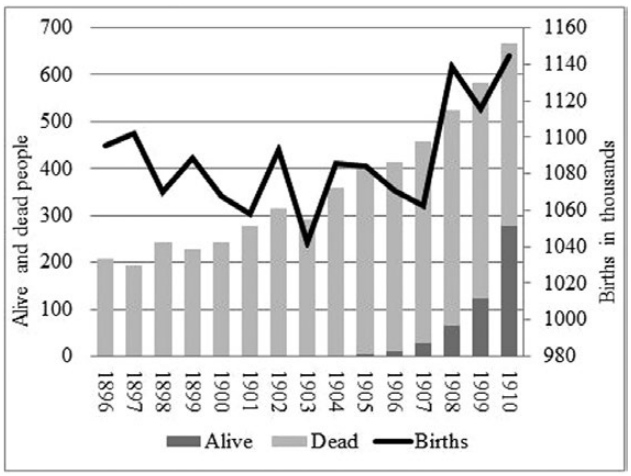

Figure 1. SSC survey: validated semisupercentenarians by cohort, alive and dead, and their number of births. Italian cohorts 1896–1910 at January 1, 2017

Although the increase in the number of centenarians is well documented today in countries with advanced demographic data, the same is not true for those aged 105 years and over, and still less for those of 110 years and over (Robine & Vaupel, 2001). After a feasibility study (Robine, Gampe, Cournil, & Vaupel, 2000; Robine & 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. These were defined as individuals who had reached the age of 110 (Jeune & Vaupel, 1999, 2001; Robine et al., 2000; Robine & Vaupel, 2002; Robine, Allard, & Jeune, 2006a; Maier, Gampe, Jeune, Robine, & Vaupel, 2010; Poulain, 2010; Jdanov, Shkolnikov, & Gellers-Barkmann, 2017; see www.super-centenarians.org). The IDL database is complemented by an international list of supercentenarians collected on the internet by Louis Epstein with the help of Robert Young (http://www.grg.org).

About 10 years later, some countries adhered to the proposal to extend the IDL database to semisupercentenarians, aged 105 years and over (Maier et al., 2010). The problem for persons of these ages is that they are harder to validate, as they are far more numerous than the supercentenarians (in Italy in the period from 2009 to the present they number around 4,600 against 102), and this makes it harder to gather the necessary information for identifying their age with certainty. In general, for supercentenarians, the preferred evidence is a birth certificate and/or baptism certificate, or an early census record if alive, and death certificate if dead, and these were available and have been checked. For semisupercentenarians, however, different countries use different methods to verify their age. At all events, reliable and detailed information is essential for valid demographic analyses (Maier et al., 2010).

Italian researchers in the Department of Social Sciences of Sapienza University in Rome and the Italian National Institute of Statistics (Istat) have been involved in collecting the data on semisuper and supercentenarians since the IDL began, first identifying and validating the Italian supercentenarians who died between 1969 and 2001, and between 2002 and 2008 (Bruzzone, Barbi, & Caselli, 2010), and then setting up a specific semisupercentenarian survey (SSC) at Istat. Since 2008 this survey has collected data about living and dead semisuper and supercentenarians (Battaglini, Capacci, Corsetti, & Marsili, 2012; Caselli, Battaglini, & Capacci, 2017), and the use of this information, together with that on deaths collected in other Istat surveys, has made it possible to collect the data for Italian centenarians for the cohorts born after 1870 who are now extinct (1870–1904).

The first aim of this work is to present an analysis of the demographic characteristics and development of the Italian semisuper and supercentenarians, living and dead, that

have been validated so far in the SSC survey, for the cohorts born between 1896 and 1910 (1904 for the supercentenarians). The second aim is to use all the available information on the deaths of 35 cohorts now extinct to provide the most complete picture possible of the demographic characteristics of the centenarians born between 1870 and 1904. The third aim is to interpret the development of the centenarians and semisupercentenarians of the various cohorts, referring to the histories of differential mortality—and, thus, of survival—in old age, using the new life tables obtained from completing the existing ones up to age 100 with those reconstructed after this age by Vincent's *Extinct - Cohort Method* (1951). The last and most important aim is to gain a better understanding of the demographic reasons for this population development, with particular reference to the changing characteristics of the gap between men and women, and also to provide material that is useful for studying the longevity of populations. In fact, in referring to the development in the survival of centenarians in the cohorts under study, the aim is to see in which ages life expectancy is extending further and in which it is not.

Data and Method

Data Collection and History of SSC Survey

As we have said, in 2008, Istat initiated a new survey (SSC survey) in order to collect data about semisuper and supercentenarians. This survey enables us to identify persons of these ages, living or dead, with an approach that eliminates from the group provided by population registers those who cannot be "validated" following the parameters fixed by the IDL. One essential condition for the validation of these persons is that each individual, if still alive, should be identified by a birth certificate if a supercentenarian, and by a certificate of living existence if semisuper, and at the end of his life by a death certificate. In the case of the Italian semisuper and supercentenarians, by linking the various information it was possible to establish with certainty if they were individuals who had reached the age of 105 and over, and, if dead, their age at decease.

The validation process is a long one, drawing on several demographic sources. Persons of these ages are first identified through an administrative source on population, the so-called POSAS survey (Italian acronym for Resident Population by Age, Sex and Marital Status). This is a survey carried out by Istat on the resident population of the Italian municipalities (about 8,000), broken down by gender, cohort and marital status on January 1st of each year. Data are obtained from each municipality through a web applications system. Thanks to POSAS we know how many people of a given cohort and/or gender and/or marital status are still alive in a municipality that has reported residents aged 105 years and over on the statistics form. Each municipality is then contacted by Istat in order to collect more detailed information on those individuals and to request the submission of documents certifying their status as alive or dead for final validation. Those still alive at age 105 and over are then "followed" year by year until death, which is then inserted in the database (date of death). As long as the individual remains alive, the validation process never stops and each single year we proceed to "re-validate" the data observed in the past. Summarizing, the variables needed for the validation and included in the Italian SSC survey are: name, date of birth, date of death, completed age in YY-DD (calculated variable), place of birth, place of residence (at death), marital status (at death), citizenship (at death), and presence/absence in the database t, t+1. All information is included in the SSC, including newspaper information or migration from/to another municipality, and any other information received from the municipality. The data collected from the SSC survey are periodically subject to record linkage operations with other Istat surveys to improve data quality.

On January 1, 2017, 8 years after the SSC survey began, the individuals being followed numbered 5,228 and 4,626 (562 men and 4,064 women) have been validated. Each record is a person in the survey, 510 still alive, and 4,116 now dead.

Other important data sources relating only to the dead are the Cause of Death Survey (CDS) and Deaths of Resident Population survey (DRP), which were used in order both to integrate the SSC database, and to reconstruct those between the ages of 100 and 104 for extinct cohorts.

Thanks to the integration of the data from the SSC, DRP, and CDS surveys, the database that we have used in this article is the most complete and accurate that is now available in Italy and certainly one of the best available in the world for semisuper and supercentenarians. It is included in the IDL database.

To sum up, the data sources employed in this paper refer to:

1. *For living persons*: Istat SSC survey data (2008–2017 years, at 1st January, individuals aged 105 years and over). Cohorts born before 1910.
2. *For dead persons*: (a) Istat SSC survey data (2009–2016 years, individuals aged 105 years and over). Cohorts born before 1910; (b) Istat CDS survey (1969–2008 years, individuals aged 100 years and over 2009–2010 years, aged 100–104 years) for all cohorts 1870–1910; (c) Istat DRP survey (2011–2016 years, for individuals aged 100–104 years).

"Extinct - Cohort Method" for Reconstructing the Italian Centenarians and New Life Tables After Age 100 for the Cohorts 1870–1904

Traditionally, life tables are closed at 100 years or, after this age, the probability of death is reconstructed by referring to theoretical mortality curves (Vaupel, Manton, & Stallard, 1979; Kannisto, 1994; Horiuchi & Wilmoth, 1998; Thatcher, Kannisto, & Vaupel, 1998; Vaupel et al., 1998; Robine & Vaupel, 2001; Barbi, Caselli, & Vallin, 2003).

In this work, as indicated in the introduction, we propose to reconstruct the life tables for all the cohorts now

extinct (1870–1904), considering their mortality history up to the last registered death. The relevant data are the deaths in the CDS and DRP surveys for individuals who died in the 100–104-years bracket, and those in the SSC and CDS surveys for individuals who died after the age of 105. For oldest persons, in the absence of migration, and for extinct cohorts of births, we could construct cohort life tables after age 100 simply by taking the deaths by age from 100 until the last survivors. We reconstruct these tables with Vincent's *Extinct - Cohort Method* (1951). Starting from the cohort's last survivor, we can determine the number of survivors at any age x after 100, by successively combining the deaths observed at preceding ages. In this case, if the survivors at age x (x = 100) are S_x and the deaths $d_{(x,\ x+1)}$ are exactly, by hypothesis, those of the life table being sought: $S_x = \sum_x^{\omega-1} d_{x,x+1}$, using this method the radix of our table is 100. The method can obviously give us the survivors of the life tables at every age from 100 to ω. In the last step, we have linked this end-of table to the table computed using the classic method for the previous ages. We must reduce the total population in the death series thus calculated to the number of survivors at the age when the conventional calculation stopped, or go back to the probabilities and complete the series of classic probabilities for all cohorts by adding the probabilities determined by means of the extinct-cohort method for age 100 and over.

Italian Semisuper and Supercentenarians Validated by Cohort of Birth: Results by SSC Survey

Figure 1 provides a picture of the Italian semisupercentenarians, distinguished by their birth cohorts 1896–1910 (Caselli et al., 2017). We can note at once that, if we exclude the cohort of those born in 1903, there is a constant growth in numbers as we pass from an older cohort to one more recent. With the exception of the cohort of 1903, in the space of a mere 15 cohorts, the contingent of semisupercentenarians tripled from the first to the last (207 in the cohort of 1896, and 666 in the cohort of 1910, respectively), and, at least until the cohort of 1907, the growth is independent of the size of the initial population (number of births). To clarify the reasons for this significant increase, we can construct an indicator proposed by Caselli (Robine & Caselli, 2005), which excludes the differential effect of births and migrations (supposing them to be zero for the generations studied after 60 years of age). We use this indicator, as the ratio of the number of individuals of each cohort aged 105 years and over to the number of persons of the same cohort who were 60 years old 45 years before: this is the semisupercentenarian rate, known as $SSCR_{60}$. Essentially this indicator measures the proportion of 60-year old persons who survived to age 105. The development of the $SSCR_{60}$ brings out very clearly the significant net increase in semisupercentenarians, however numerous they were at 60 years of age ($SSCR_{60}$ for the total is equal to 0.04 and 0.10 per 100 for the first and last cohort, respectively; Figure 2). The $SSCR_{60}$ allows us to study changes in old-age survival over time and compare them by cohort, eliminating the effects of other determinants on the size of the semisuper-centenarian population, such as migration, fertility, infant mortality, and also young and adult mortality, which was still high for the Italian cohorts and varied widely between genders, particularly for men in the cohorts involved in the First World War, which left around 600,000 young men on the field of battle (Glei, Bruzzone, & Caselli, 2005). In addition, we can see from Figure 2 that the anomaly identified for the generation of 1903 continues only for the women, conclusively excluding—for them, at least—the role of reduced births in the more reduced number of those who reached the age of 105 in this cohort.

In general, we can say that the result of the increase in the $SSCR_{60}$ that can be seen when we move from the first to the last cohort is explained by the decline in mortality in ages after 60 (Caselli & Egidi, 2011; Caselli, 2016). We shall give further attention to this aspect later.

Figure 2, which also draws attention to the distribution of semisupercentenarians distinguished by gender, brings out at the same time a greater number of women and a higher growth than men as we move from the first to the last cohort, although there has been a significant increase for the men in the more recent cohorts. Recalling that on January 1, 2017 the semisupercentenarians validated (cohorts 1896–1910) numbered 4,626 and that there were 4.064 women and 562 men, the W/M ratio, known as the Femininity Ratio (FR) (Robine, Caselli, Rasulo, & Cournil, 2006b), is equal to 7.2. Regarding the individual cohorts, the lowest relation is that for the first cohorts, with values of around 3.0 women for each man. It then gradually rises, reaching values of around 9 for the more recent cohorts. With the passage of time, then, there emerges an increase in the gap between the two genders that wholly favors women.

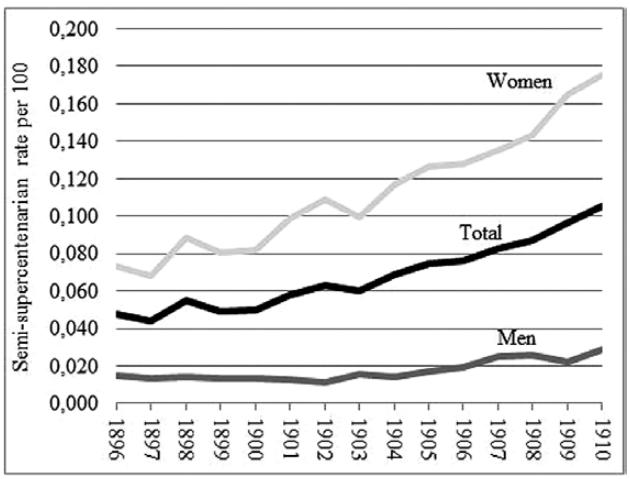

Figure 2. SSC survey: trends of semisupercentenarians rates ($SSCR_{60}$) per 100. Italian cohorts 1896–1910.

The representation of the supercentenarians is interesting (Supplementary Figure 1). In Italy, there were 102 in the cohorts between 1896 to 1905, of whom 95 were women and 7 men (FR equal to 13.6, higher than 10.4 in IDL supercentenarians database) (Gampe, 2017). The cohort of 1889 included the super-validated Antonio Todde, who held the title of World's Oldest Living Man when he passed away on January, 2002 at the age of 112 years and 346 days (Poulain et al., 2004, 2006; Caselli et al., 2006b). The cohort of 1899 included Emma Morano, who was regarded as the World's Oldest Living Person when she passed away on April 15, 2017 at 117 years and 137 days (Jeune, Heiner, & Vaupel, forthcoming; Caselli et al., 2017).

As for the 102 supercentenarians validated and those of the same cohorts who reached the age of 100 (the extinct-cohort method has allowed us, as we have said, to reconstruct 51,972 centenarians), the proportion of centenarians reaching the age of 110 halts at 2.0 per thousand. This is fairly close to the 2.9 per thousand identified for French centenarians in the IPSEN survey (Allard, Vallin, Andrieux, & Robine, 1996). Among the supercentenarians, the transition from the first to the last cohort does not show a constant growth as for the semisupercentenarians, but, once again, there is an interruption in the trend for the cohort of 1903 and, in this case, for that of 1902 as well (Figure 1 and Supplementary Figure 1).

In any case, it is clear that in Italy, as elsewhere, reaching the age of 105 and, still more, 110, is a privilege enjoyed by a growing number of people, but a privilege that is, to a very great extent, reserved for women, who certainly live longer. Individuals still alive of the cohorts between 1899 and 1904 died in the course of 2017.

Mortality and Survival by Cohorts Born From 1870 and 1904: Results

Longevity of centenarians and semisupercentenarians by cohort

To analyze the longevity of centenarians (aged 100 years and over), we refer to mortality cohort indicators, as well as survival indicators, using deaths and populations reconstructed with the extinct-cohort method. In this way we can link the survival history of the semisuper and supercentenarians with their immediately preceding history from the age of 100 on. First of all, in Figure 3 and Supplementary Table 1, we can see the significant development in centenarians for the cohorts born between 1870 and 1904, while Supplementary Figure 2 also shows the characteristics of this development, by both gender and age. In the 35 cohorts considered, no fewer than 51,972 persons reached the age of 100. On the basis of a relative indicator like the *CDTc* (Centenarian Doubling Time by Cohort), which measures the length of cohorts/period in which the number of centenarians doubles—equal to ($ln2/r$), where r is annual rate of increase in the number of centenarians—the number of centenarians in these cohorts doubled approximately every 9.4 cohorts/years. The number of centenarian women doubled every 8.9 cohort/years, and for men every 11.9. Supplementary Table 1 also shows how rapidly the doubling for the semisupercentenarians (SSDTc) took place in the 35 cohorts considered. In particular, the women doubled approximately every 8 cohorts/years, against about 12 for the men.

We can gain a summary idea of the development by age and gender from the pyramids in Supplementary Figure 2, constructed for four groups of cohorts (the first, the last, and two intermediate groups, one of which includes Antonio Todde and the other Emma Morano). If we move from the first to the last group, we can see that for both genders the pyramid broadens constantly in the early and extreme ages of life, while the number of women grows constantly for all ages. Overall, for the oldest cohorts the relation between centenarian women and their male peers (said Femininity Ratio-FR, as in Robine & Caselli, 2005) is equal to 2.5, while in the group of 20th-century cohorts it is equal to 5.1 (a value emerging from previous analyses on data by calendar year) (Robine & Caselli, 2005). The FR grows with the succession of cohorts, just as for the semisupercentenarians, and therefore grows as the age of death increases.

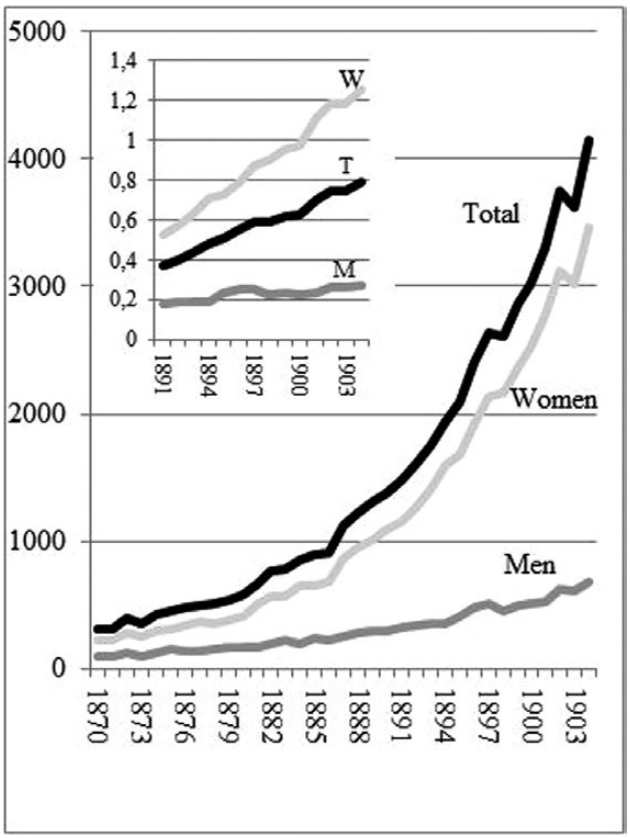

Figure 3. Number of centenarians reconstructed by Extinct - Cohort Method, as the trend of deaths for the Italian cohorts 1870–1904 and the Centenarian Rate (CR_{60}) per 10,000.

In particular, a comparison of the life table of the most recent cohorts (1900–1904) of female survivors in Supplementary Figure 3 with those of the life table of the first group (1870–1874) shows that the survival of centenarian women has increased in all ages between 100 and 104, and in ages over 105 too (validated data of the SSC survey). Hence, not only do more members of the most recent cohorts reach the threshold of 100, but also, once this threshold has been reached, their probability of survival increases at all later ages, thus indicating the presence of a decline in mortality, at least up to 110–112 years. Though fewer of the men in the most recent cohorts reach the age of 100 and have a lower survival than women, they too show an equally positive development in survival levels. For them, however, the growth halts shortly before their 110th birthday, meaning that, on average, the men's age at death is lower. This behavior is particularly notable for survivors after the age of 105, and is also generally accepted in the literature on the subject (Wilmoth & Lundstrom, 1996; Wilmoth & Robine, 2003; Wilmoth, Deegan, Lundström, & Horiuchi, 2000).

Turning now from the survival function to the estimate of life expectancy after 100 years, women born between 1900 and 1904 have little more than 2 remaining years, and men 1.9 (Supplementary Table 2, see also Figure 4). However, in the development from the first to the last group of cohorts, the life expectancy of female centenarians moves from 1.9 to 2.2 years, with a slight but constant growth trend, while their male peers move from 1.6 to 1.9 years. These values are in line with those found for the cohorts 1886–1890 in Sweden (1.69 years for men and 1.98 years for women; Bourbeau & Desjardins, 2007, p. 179) and for the French centenarians in the IPSEN survey referring to period data (1.77 years for men and 2.22 years for women; Allard et al., 1996, p. 73). If we consider the maximum values reached between the first and last group for both genders of Italian centenarians, then those born in the early 20th century were able to enjoy an average of about 4 months of life more than centenarians born 30–34 years earlier.

The growing number of centenarians through the survival history of 35 extinct cohorts

Analyzing the development of extreme age at death for the Swedish population (between 1861 and 1999), together with that of a group of validated supercentenarians in six countries, Wilmoth and his colleagues (Wilmoth & Lundstrom, 1996; Wilmoth & Robine, 2003; Wilmoth et al., 2000) concluded that the growth trend was the same for the two populations, but the higher or lower values, like the differences observed, could be explained simply as a function of different population size and a different pattern of old-age mortality. Using the supercentenarian rate by cohort in this work, we found that, eliminating the effect of the size of the population at age 60, the significant growth identified among the semisupercentenarians as we move from the first to the last cohorts could be explained, like the gender differences, by the differential development in old-age survival. Now, starting from the survivors at age 60 in the life tables of the cohorts 1870–1904, we can clearly say that the role of the increase in survival was due to a decline in mortality at these ages.

For the women the survival curve after 60 hardly changes between cohort 1870 and 1904 (Figure 5). Since then, it has gradually shifted to the right. The most recent cohorts who reach the threshold of 90 and 100 (and even 105) years are much more numerous, because they have been able to enjoy a greater number of years gained in the immediately preceding ages. Indeed, in the cohort of 1870 half the survivors at 60 died before reaching 76 years, while in the 1904 cohort half of them were still alive at 82 years. Moreover, whereas only 6.4% of the 1870 cohort reached the age of 90, three times that number, 19.1%, of the 1904 cohort were still alive. At the age of 100 the proportion rose by 0.1% and 11%, respectively.

The survival curve for men at once brings out the significance of old-age mortality on the differences observed between the two genders in the number of centenarians and, obviously, the semisupercentenarians. Men have recouped far fewer years of life: for the first cohort, 50% died before reaching the age of 72, and for the last, before 77. Only 4% and 8%, respectively, of the initial 60-year olds reached the age of 90, against, as we have seen, 6% and 19% for women. The number of men reaching 100 is very limited:

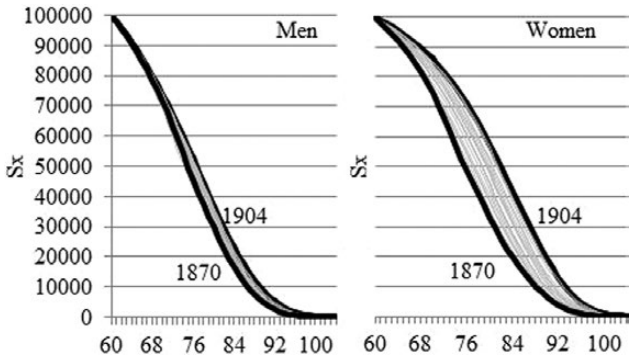

Figure 4. Survival (S_x) by sex and cohort, after age 60 years. Italian cohorts 1870–1904.

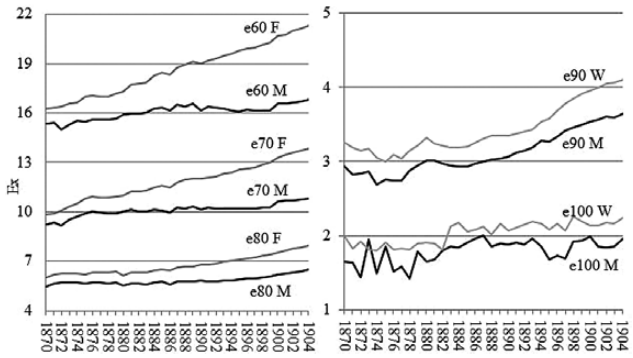

Figure 5. Life expectancy by sex and cohort, at ages 60, 70, 80, 90, and 100 years. Italian cohorts 1870–1904.

0.05% of the 60-year olds of 1870, and little more than 3% of those of 1904.

The curves of life expectancy at 60, 70, and 80 years of age explain still more clearly the disadvantages of the male cohorts, particularly if we consider the increasing gap as we move from the first to the last cohort (Figure 4).

Conclusion and Discussion

In this work, we have been able to examine the development of the semisupercentenarians by cohort, thanks to the data collected in the SSC Italian survey. For the cohorts born from 1896 to 1910, these data are extremely reliable and show a significant increase in the population of centenarians and of semisupercentenarians too, in absolute and relative terms. Italian women are more likely to cross the threshold of 100 years and the Femininity Ratio grows with the succession of cohorts, just as for the semisupercentenarians.

A clearer explanation of the importance of mortality development in old age in determining the increase in the gender gap between centenarians can be gained by looking at the growing gap in life expectancy (Figure 4) between women and men at 60 and 70 years from one cohort to the next. For example, at the age of 60 the life-expectancy gap for men and women in the 1870 cohort was about 1 year, while it was 4.5 years for that of 1904. This gap certainly increased, partly as a result of the deterioration in the conditions of life for the men in our cohorts. We may note that the men gain no years of life until the cohorts of the late 19th century. The stagnation involves all the male cohorts that took part in the First World War (Caselli, 2016). Their numbers reduced at young adult age by the losses in that conflict, they found themselves paying the consequences in later years too, at least until age 80, probably as a result of adopting habits such as cigarette smoking (widespread among soldiers during the First World War), which increased their risk of death, particularly from lung cancer (Caselli, 2016). At the same time that men suffered the effects of a life history that had involved risks that endangered their health, Italian women in the same cohorts, who had been marginalized from the world of work and protected by a traditional culture, were, as a result, also protected from more harmful life styles, and were therefore able to recoup more years of life, gradually increasing the gender gap.

Only after the age of 90—but by then the number of those who can reach 100 is much reduced, and so more selected—does the average survival rate start to grow, as for women (Caselli et al., 2006a; Caselli et al., 2017). Starting from the cohorts of the 20th century, men too gain in survival at every old age, and this has a positive impact on their longevity and thus on the increase in centenarians in these cohorts too: the effects are clearly brought out by the semisupercentenarian rate too (Figures 2 and 3).

In fact, the increase in life expectancy for the old and the oldest old occurred at a different pace and in different stages, depending on gender and age. The life expectancy of 60- and 70-year-old women, like that of men, began to increase with the first cohorts. Then, starting from the cohorts of the First World War, as we said, it was interrupted for men, while for women it continued to rise. Positive developments for both genders at every age only becomes visible with the first 20th-century cohorts, when men and women in the years 1970–1975 experienced the first real decline in old-mortality, thanks to the decrease in mortality for cardiovascular diseases, a subject that has been dealt with by various authors (Caselli, 2016; Caselli & Egidi, 2011). Obviously, the important role of what is known as the cardiovascular revolution also involved these cohorts at later ages, starting from years 1970 to 1975. As Meslè (2006) and Vallin (2006) in France, and Caselli in Italy (2016) have written, the positive effects of the reduction in mortality from cardiovascular diseases, as well as bronchitis and pneumonia following the drop in influenza brought about by the widespread use of vaccines, had a positive impact on the longer survival of our cohorts, both male and female, at 90 and 100 years. We can see that all these effects had an important role in increasing the number of centenarians, too.

In short, if, as many writers have claimed, the growing number of centenarians and supercentenarians should be related to the size of the initial population, then equally important for that growth is diminishing mortality in old ages. Indeed, by removing the effect of the initial population, we have been able to show that for the cohorts under study the observed increase from the first cohorts to those most recent, the increase is due to the favorable development in survival in old ages and the consequent reduction in mortality at these ages. We have also seen that the different development of life expectancy observed in men and women after the age of 60 is responsible for the increased gender gap in extreme ages of life.

Considering the rate of increase of our population, if we were to extrapolate the results observed for the last cohorts, we would have to conclude that, in the absence of unforeseeable events, the cohorts following those examined so far should show mortality levels in old ages that are still lower and that will further increase the number of years lived in old age before and after the age of 100, at least up to 112 years. Around this age, for both genders, but for women in particular, a kind of resistance to further progress seems to appear in our analysis. This result might suggest a gradual closing of the gender gap in the future as the cohorts of the second decade of the 20th century become centenarians. But, as we have already said, this is also a very important result for studies on longevity, as it confirms what has been seen in other studies drawing attention to the existence of a kind of plateau in the decline in mortality at these ages (Barbi, 2017; Gampe, 2017; Gavrilov, Krut'ko, & Gavrilova, 2017).

Survival after 110 years remains in general the unknown factor, which numerous studies have referred to, partly

with a view to understanding if there may be an upper limit to human longevity (Luy, Butz, & Caselli, 2013; Olshansky et al., 1990; Wilmoth, 1997). As we have seen, so far all studies seem to agree that there is a stagnation in average mortality levels after 111–114 years (Gampe, 2017), suggesting there is a barrier that can be overcome only by a very few. Barbi (2017) in a recent study applying a battery of eight proportional hazard models, estimated from the survival trajectories of the Italian SSC survey, also confirmed the existence of the cohort effects and on mortality plateau after 112 years. More recent scientific publications suggest that human longevity records have stopped increasing. Certainly, in the last 20–25 years the maximum reported age at death fluctuated around 115 years, although some persons live beyond this age, like Emma Morano in Italy, who died in 2017 at the age of 117 years and 137 days. Whether or not there is a limit is hotly debated (Barbi et al., 2003; Olshansky et al., 1990; Wilmoth, 1997). The international journal *Gerontology* (2017, Experimental Section) recently published two contrasting opinions that are of interest to both demographers and biologists, one by Vijg & Le Bourg (2017), who try to show "why human life span is limited and cannot reach the considerably longer life spans of several other species," and the other by Gavrilov et al. (2017), who claim there is no convincing evidence that we have reached the limit of the human life span, although the mortality of supercentenarians has not decreased. They said "the future of human longevity is not fixed and will depend on human efforts to extend life span." But, how, when, and for whom?

We must wait and see if the recent scientific evidence is contradicted or verified by the behavior of the future supercentenarians. What we believe is that the extreme ages of life will be reached by an ever larger number of persons, but what we hope is that they may enjoy reasonable conditions of physical and mental health (Franceschi & Bonafé, 2003; Olshansky, Carnes, & Cassel, 1990; Paolisso et al., 2000; Willcox, Willcox, & Poon, 2010; Yashin et al., 2000). This last condition is certainly important at an individual level, but also absolutely necessary for containing public expenditure in our societies.

Obviously, if our analysis has the virtue of supplying for the first time the number and the histories of survival for the semisupercentenarians of one of the largest European countries, it does, however, have the limitation of not being able to draw on micro-information that would allow us to move from describing to explaining the processes studied and, in particular, to identifying the factors that have allowed a growing number of men and women to reach such advanced ages. To do this, one would need to have micro data collected by ad-hoc surveys with information concerning variables able to establish relations with the process under study. Longevity is a multidimensional process that requires far more information than that supplied by demographics if it is to be interpreted. The demographic data are indispensable for measuring the phenomenon in relation to extensive populations, and not only for small groups, but these data need to be integrated with more information concerning some individual and familiar characteristics and the geographical context in which the individual lives.

Starting from the data collected so far for Italy, but also available for the various municipalities of birth and residence of semisupercentenarians, in future we shall be able to move in this direction to find a more adequate explanation of the phenomenon. This can be done by identifying geographic areas of longevity and seeking information on the characteristics of family, marriage rate, fertility and migration for our semisupercentenarians in the municipalities that make up these areas, as has been done for Sardinian centenarians (Caselli et al., 2006b; Poulain et al., 2006). However, it will not be possible to collect information on individual risk factors for the individuals in our cohorts, as our ultra-centenarians are now extinct.

Supplementary Material

Supplementary data is available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

Author Contributions

G. Caselli planned the study, supervised all the paper and wrote the paragraphs: Introduction; Mortality and survival by cohorts born from 1870 to 1904: results; Conclusion and Discussion. M. Battaglini performed all statistical analysis, realized figures and tables and wrote the paragraph Italian Semi-super and supercentenarians validated by cohort of birth: results by SSC survey; G. Capacci contributed to revising the paper, the statistical analysis and wrote the paragraphes: Data Collection and History of SSC Survey; "Extinct - Cohort Method" for Reconstructing theItalian Centenarians and New Life Tables After Age 100 for the Cohorts 1870–1904.

Conflict of Interest

None reported.

References

Allard, M., Vallin, J., Andrieux, J-M., & Robine J-M. (1996). Health and mortality among elderly populations. In G. Caselli, & A. D. Lopez (Eds.), *Search of the secret of centenarians: A demographic and medical survey about centenarians* (pp. 81–86). Oxford: Clarendon Press.

Barbi, E. (2017). Cohort effects and mortality plateau. Presentation to 13th Supercentenarian Workshop, Rostock, 15–16 May.

Barbi, E., Caselli, G., & Vallin, J. (2003). Trajectories of extreme survival in heterogeneous population. *Population*, **58**, 43–66. doi:10.2307/3246644

Battaglini, M., Capacci, G., Corsetti, G., & Marsili, M. (2012). Semi-super and supercentenarians in Italy: Implementation of a longitudinal database. Presentation to European Population Conferecence, EAPS, Stockholm, 12–15 June.

Bourbeau, R., & Desjardins, B. (2007). Mortality at extreme ages and data quality: The Canadian experience. In J-M. Robine, E. M. Crimmins, S. Horiuchi, & Y. Zeng (Eds.), *Human longevity, individual life duration and the growth of the oldest-old population* (pp. 167–185). Berlin: Springer. doi:10.1007/978-1-4020-4848-7_8

Bruzzone, S., Barbi, E., & Caselli, G. (2010). Italian Supercentenarians: Age validation of deaths from 1969 to 2000. In H. Maier, J. Gampe, B. Jeune, J-M. Robine, & J. W. Vaupel (Eds.), *Supercentenarians, demographic research monographs* (pp. 137-150), **7**, Berlin: Springer, doi:10.1007/978-3-642-11520-2_8

Caselli, G. (2016) The gender gap in survival: A new perspective. *The Italian Journal of Gender-Specific Medicine*, **2**, 75–82. doi:10.1723/2446.25650

Caselli, G., Battaglini, M., & Capacci, G. (2017). Differential characteristics of Italian semi-super and supercentenarians of the 'SSC' database: A cohort approach. Presentation to 13th Supercentenarian Workshop, Rostock, 15–16 May.

Caselli, G., & Egidi, V. (2011). Una vita più lunga e più sana. Riflessioni sul passato per immaginare il futuro. In A. Golini, & A. Rosina (Eds.), *Il secolo degli anziani. Come cambierà la società italiana* (pp. 29–45). Bologna: II Mulino - Prismi.

Caselli, G., Pozzi, L., Vaupel, J. W., Deiana, L., Pes, G. M., Carru, C.,…Baggio, G. (2006b). Family clustering in Sardinian longevity: A genealogical approach. *Experimental Gerontology*, **41**, 727–736. doi:10.1016/j.exger.2006.05.009

Caselli, G., Vaupel, J.W., & Yashin, A. I. (2006a). Explanation of the decline in mortality among the oldest-old: A demographic point of view. In J-M. Robine, E. M. Crimmins, S. Horiuchi, & Y. Zeng (Eds.), *Human longevity, individual life duration and the growth of the oldest-old population* (pp. 395–413). Berlin: Springer. doi:10.1007/978-1-4020-4848-7_17

Franceschi, C., & Bonafè, M. (2003). Centenarians as a model for healthy aging. *Biochemical Society Transactions*, **31**, 457–461. doi:10.1042/

Gampe, J. (2017). Update of mortality estimates at highest ages. Presentation to 13th Supercentenarian Workshop, Rostock, 15–16 May.

Gavrilov, L. A., Krut'ko, V. N., & Gavrilova, N. (2017). The future of human longevity. *Gerontology*, **63**, 1–3. doi:10.1159/000477965

Glei, D. A., Bruzzone, S., & Caselli, G. (2005). Effects of war losses on mortality estimates for Italy. *Demographic Research*, **4**, 61–86. doi:10.4054/demres.2005.13.15

Horiuchi, S., & Wilmoth, J. R. (1998). Deceleration in the age pattern of mortality at older ages. *Demography*, **35**, 391–412.

Jdanov, D. A., Shkolnikov, V. M., & Gellers-Barkmann, S. (2017). The international database on longevity. Presentation to 13th Supercentenarian Workshop, Rostock, 15–16 May.

Jeune, B., Heiner, M., & Vaupel, J. W. (forthcoming). *Advances in research on centenarians and supercentenarians*. Springer.

Jeune, B., & Vaupel J. W. (Eds.). (1999). *Odense monographs on population aging 6: validation of exceptional longevity*. Odense: Odense University Press.

Jeune, B., & Vaupel, J. W. (Eds.). (2001). *Validation of Exceptional Longevity. Monographs on Population Aging*, **6**. Odense: Odense University Press.

Kannisto, V. (1994). *Development of oldest-old mortality, 1950–1990: Evidence from 28 developed countries*. Odense: Odense University Press

Luy, M., Butz, B., & Caselli, G. (Eds.), (2013). Determinants of unusual and differential longevity. *Thematic Issue of Vienna Yearbook of Population Research*, **11**, 1-13.

Maier, H., Gampe, J., Jeune, B., Robine, J-M., & Vaupel, J. W. (Eds.), (2010). *Supercentenarians. Demographic research monographs*, **7**. Berlin: Springer, doi:10.1007/978-3-642-11520-2_1

Meslé, F. (2006). Causes of death among the oldest-old: Validity and comparability. In J-M. Robine, E. M. Crimmins, S. Horiuchi, & Y. Zeng (Eds.), *Longevity, individual life duration and the growth of the oldest-old population* (pp. 191–214). Berlin: Springer.

Olshansky, S. J., Carnes, B. A., & Cassel, C. (1990). In search of Methuselah: Estimating the upper limits to human longevity. *Science (New York, N.Y.)*, **250**, 634–640.

Paolisso, G., Manzella, D., Rizzo, M. R., Barbieri, M., Gambardella, A., & Varricchio, M. (2000). Effects of glucose ingestion on cardiac autonomic nervous system in healthy centenarians: Differences with aged subjects. *European Journal of Clinical Investigation*, **30**, 277–284.

Poulain, M. (2010). On the age validation of supercentenarians. In H. Maier, J. Gampe, B. Jeune, J-M. Robine, & J. W. Vaupel (Eds.), *Supercentenarians, demographic research monographs* (pp. 3–30). **7**, Berlin: Springer. doi:10.1007/978-3-642-11520-2_1.

Poulain, M., Pes, G. M., Carru, C., Ferrucci, L., Baggio, G., Franceschi, C., & Deiana L. (2006). The validation of Exceptional Male longevity in Sardinia. In J-M. Robine, E. M. Crimmins, S. Horiuchi, & Y. Zeng (Eds.), *Longevity, individual life duration and the growth of the oldest-old population* (pp. 146–166). Berlin: Springer. doi:10.1007/978-1-4020-4848-7_7

Poulain, M., Pes, G. M., Grasland, C., Carru, C., Ferrucci, L., Baggio, G.,…Deiana, L. (2004). Identification of a geographic area characterized by extreme longevity in the Sardinia island: The AKEA study. *Experimental Gerontology*, **39**, 1423–1429. doi:10.1016/j.exger.2004.06.016

Robine, J-M., Allard, M., & Jeune, B. (2006a). *Global Ageing: Issues and Action*. 2006; 4 (1: Special issue eds. by L. Poon), 6-15.

Robine, J-M., & Caselli, G. (2005). An unprecedented increase in the number of centenarians. *Genus*, **61**, 57–82.

Robine, J. M., Caselli, G., Rasulo, D., & Cournil, A. (2006b). Differentials in the femininity ratio among centenarians: Variations between northern and southern Italy from 1870. *Population Studies*, **60**, 99–113. doi:10.1080/00324720500466000

Robine, J-M., Gampe, J., Cournil, A., & Vaupel, J. W. (2000). *IDL, the International Database on Longevity*, INSERM, Montpellier, France, Max Planck, Institute for Demographic Research, Rostock, Germany

Robine, J. M., & Vaupel, J. W. (2001). Supercentenarians slower ageing individuals or senile elderly? *Experimental Gerontology*, **36**, 915–930. doi:10.1016/s0531-5565(00)00250-3

Robine, J-M., & Vaupel, J. W. (2002). Emergence of supercentenarians in low mortality countries. *North American Actuarial Journal*, **6**, 54–63. doi:10.1080/10920277.2002.10596057

Thatcher, A. R., Kannisto, V., & Vaupel, J. W. (1998). *The force of mortality at ages 80 to 120*. Odense: Odense University Press.

Vallin, J. (2006) Mortality differences by sex among the oldest-old. In J-M. Robine, E. M. Crimmins, S. Horiuchi, & Y. Zeng (Eds.), *Longevity, individual life duration and the growth of the oldest-old population* (pp. 333–352). Berlin: Springer.

Vaupel, J. W., Carey, J. R., Christensen, K., Johnson, T. E., Yashin, A. I., Holm, N. V.,…Curtsinger, J. W. (1998). Biodemographic trajectories of longevity. *Science*, **280**, 855–860. doi:10.1126/science.280.5365.855

Vaupel, J. W., Manton, K. G., & Stallard, E. (1979). Impact of Heterogeneity in individual frailty on the dynamics of mortality. *Demography*, **16**, 439–454. doi:10.2307/2061224

Vijg, J., & Le Bourg, E. (2017). Aging and the inevitable limit to human life span. *Gerontology*, **63**, 432–434. doi:10.1159/000477210

Vincent, P. (1951). La Mortalité des vieillards. *Population*, **6**, 181–204, doi:10.2307/1524149

Willcox, D. C., Willcox, B. J., & Poon, L. W. (Eds.). (2010). Centenarian studies: Important contributors to our understanding of the aging process and longevity. *Current Gerontology and Geriatric Research*, Vol. 2010, p. 6. doi:10.1155/2010/484529

Wilmoth, J. R. (1997). In search of limits: What do demographic trends suggest about the future of human longevity. In W. W. Kenneth, & E. F. Caleb (Eds.), *Between zeus and salmon: The biodemography of longevity* (pp. 38–64). Washington D.C.: National Academy Press.

Wilmoth, J. R., Deegan, L. J., Lundström, H., & Horiuchi, S. (2000). Increase of maximum life-span in Sweden, 1861-1999. *Science*, **289**, 2366–2368.

Wilmoth, J. R., & Lundstrom, H. (1996). Extreme longevity in five countries: Presentation of trends with special attention to issues of data quality. *European Journal of Population = Revue Europeenne De Demographie*, **12**, 63–93.

Wilmoth, J. R., & Robine, J-M., (2003). The world trend in maximum life span. *Population and Development Review, Sup: Life Span: Evolutionary, Ecological, and Demographic Perspectives*, **29**, 239–57.

Yashin, A. I., De Benedictis, G., Vaupel, J. W., Tan, Q., Andreev, K. F., Iachine, I. A.,…Franceschi, C. (2000). Genes and longevity: Lessons from studies of centenarians. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, **55**, B319–B328.