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Later-Life Mortality and Longevity in Late-18th and 19th-Century Cohorts.
Where Are We Now, and Where Are We Heading?

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ABSTRACT

The limits to human lifespan are a widely discussed topic. Yet, later-life mortality and longevity are generally studied from a genetic perspective, while the social dimension has received less attention. This paper gives a systematic overview of trends in later-life mortality and longevity for cohorts that were born in the late 18th and 19th century, and shows that the average population and the top survivors from cohorts born between 1800 and 1850 were already growing older. These improvements in human survival were similar for both of the sexes among the top survivors, whereas gender equality in the life expectancy at age 50 grew rapidly in cohorts born after 1880. Differences between populations were determined by the disease environment, availability of food, and local diets, while lifestyles and social support from spouses and kin affected later-life expectancy and longevity within these populations. These findings have major implications on how we view the demographic and epidemiological transition, and forces us to reconsider existing explanations for improvements in survival during the 19th century. However, in order to find out the determinants of later-life mortality, external validity of results, blind spots due to missing data, and familial clustering need to be studied more thoroughly.

Keywords: Longevity, Later-life Mortality, Literature Review, 19th Century, Historical Trends, Sex Differences, Environmental Effects, Household, Social Support, Socioeconomic Status

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1 INTRODUCTION

Since the second half of the 19th century, mankind has been breaking the limits to life expectancy[1] (Oeppen & Vaupel 2002). The mean survival at birth increased mainly due to a large decrease in infant and child mortality – and has been studied thoroughly – whereas the impact of declining mortality later in life on the rise in life expectancy is less well understood. Until recently, few indications existed on when most people died or how long the upper percentiles of 19th-century cohorts lived. But with the ever-increasing digitization of data on 19th-century populations, a diverse body of literature has grown in which researchers use microdata to study later-life mortality (life expectancy at age 50) or longevity (top percentage of long-lived cohort members) in 19th-century cohorts. This paper discusses the studies that have applied these microdata against the background of the lengthening lives in pre-20th-century cohorts and interprets how novel insights give new directions for future research.

Two topics are discussed in this paper. First, available historical demographic data on later-life mortality and longevity in 19th-century cohorts are presented to find out when people started to live longer. Speed and timing of improvements in human survival imply how strongly the boundaries of human survival are coded into our DNA. Universal, long and steady increases in survival for both the average population and the top survivors show that non-genetic effects have a large impact on the maximum human lifespan. The degree to which later-life mortality and longevity are man-made is further stressed by the growth of a gender gap in later-life expectancy for cohorts born in the second half of the 19th century. The gender inequalities in the longevity revolution further emphasize that a search for non-genetic determinants of longevity is needed and can give an indication of why we have been growing increasingly older for the past 200 years.

Second, our understanding of how non-genetic factors affect later-life mortality has only scratched the surface. The study of historical longevity is still in its infancy, and has not developed a research framework. As a result, publications on the topic are scattered over multiple journals and test a wide range of hypotheses on various populations from different time periods. To be able to discuss this corpus of literature, research findings are organized by the different mechanisms that are expected to be at work: environmental circumstances, household composition, social support, socioeconomic status, and behavior. In this paper, I will discuss all findings, their validity, and implications for further research for each of these subfields in order to construct a framework that gives direction for further research.

2 RESEARCH FINDINGS

2.1 HISTORICAL TRENDS IN LATER-LIFE MORTALITY AND LONGEVITY

Multiple studies have been using historical demographic data to study inheritance patterns of later-life mortality and longevity (cf. e.g. Cilliers & Fourie 2012; Cournil, Legay & Schächter 2000; Houde, Tremblay & Vézina 2008; Matthijs, Van de Putte & Vlietinck 2002). But, as most authors themselves state, the effects of genetics should not be overstated. Multiple twin studies have estimated that 73-85% of the length of the lifespan, i.e. age-at-death, is determined by non-genetic effects[2] (Gögele et al. 2011; Herskind et al. 1996; Kerber, O'Brien, Smith & Cawthon 2001; Mitchell et al. 2001). Rapid increases in later-life expectancy for both the general population and the longest-living over the past 200 years as well as the development of a gender gap in later-life expectancy emphasize the importance of non-genetic effects on survival in later life. These changes in later-life mortality can hardly be attributed to biological factors as evolutionary changes of this kind normally do not occur within only 3 to 4 generations. Therefore, the rapid improvements in later-life expectancy and longevity must have been caused by changes in human living conditions.

1 It is important to note that lifespan, longevity and life expectancy are different concepts. Lifespan gauges the time an individual was alive: the age at death. Life expectancy is the mean number of years that population members lived after a certain age, and longevity defines the top survivors of a cohort.

2 As longevity is likely to cluster within families, there is a strong indication that the heritability score of the top survivors of a cohort is significantly higher than that of the average population (Sebastiani, Nussbaum, Andersen, Black & Perls 2015). Nevertheless, it is highly unlikely that the familial clustering of longevity is mostly dependent on genetic factors.

2.2 TRENDS IN LATER-LIFE EXPECTANCY AND LONGEVITY

Historical trends in later-life mortality and longevity can be retrieved from two different data sources: cohort life tables and small-scale population reconstructions. Cohort data from statistical agencies show that both the average population and long-lived individuals continued to live longer in Western Europe in the latter half of the 19th century. For people born between 1850 and 1923, both the life expectancy at age 50 and the average lifespan of the top 1% of survivors increased in a linear fashion (Human Mortality Database 2016; Statistisches Bundesamt 2006). As shown in Figure 1, these increases in lifespan were similar for Denmark, Finland, France, Germany, Iceland, Italy, the Netherlands, Norway, Sweden, and Switzerland. In a period of almost 75 years, the oldest in society grew between 5.9 to 10.6 years older, while the general population saw its life expectancy at age 50 rise between 5.2 to 9.7 years. These increases in later-life expectancy should come as no surprise, as these individuals reached age 50 after 1900 when infant and child mortality began to decline rapidly. Moreover, the top 1% of the populations died after WWII, and were known to have grown older over time.

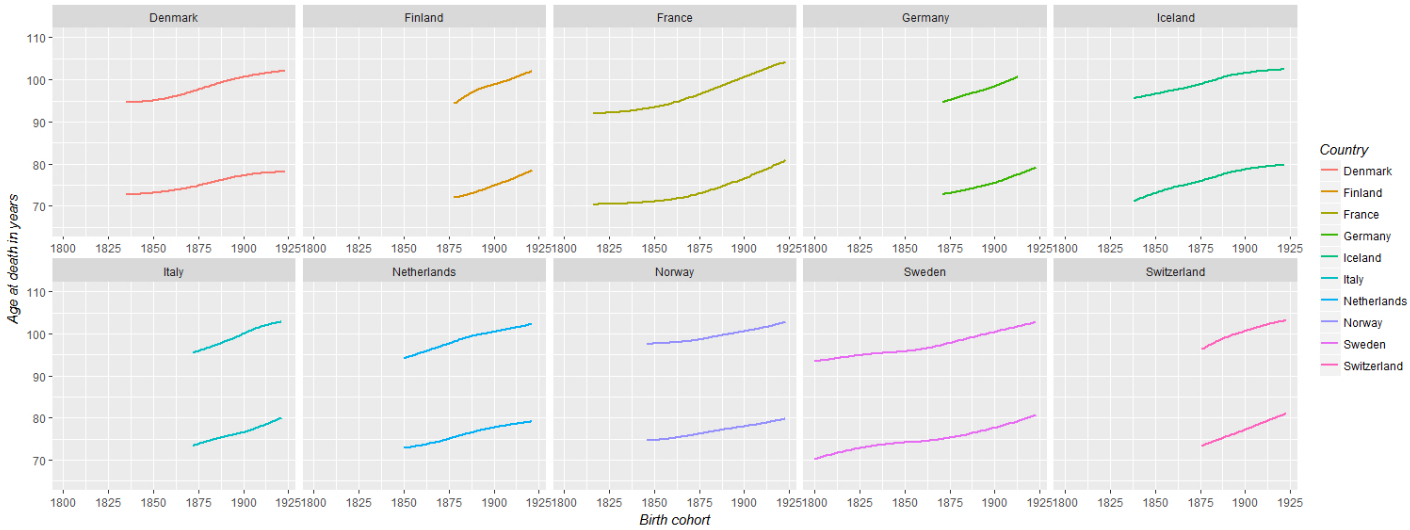
Little is known about later-life survival in cohorts that were born before 1850. Projections on the growth of life expectancy for these cohorts have been made by studying the Swedish cohort data (Wilmoth 2000). In Sweden, the maximum reported age at death continuously increased for the 1760-1860 cohorts, but at a slower pace than cohorts which were born in the second half of the 19th century. Although this trend cannot be confirmed with countrywide data, an estimation on earlier trends can be made by comparing regional population reconstructions, as they seem to capture trends for the 1850-1900 period rather well.[3] Enquiries on the Scanian Economic Demographic Database found that the life expectancy at age 50 increased in a linear fashion for 18th- and early 19th-century cohorts in Southern Sweden (Alter, Dribe & Van Poppel 2007; Bengtsson & Broström 2009; Bengtsson & Lindström 2000, 2003). This trend, however, did not apply for the Sami 1770-1850 cohort in northern Sweden, as life expectancy at age 50 and age 80 remained stable for men and even decreased for women (Karlsson 2016). Later-life expectancy and longevity thus seem to have increased in the less isolated regions of Sweden, but decreased for the Sami in northern Sweden.

Besides Sweden, data on pre-1850 cohorts is available for five other Western European countries and two settler populations. Trends in later-life expectancy for early-19th-century cohorts have also been estimated for Belgium, England, Finland, the Netherlands, and Switzerland. Studies on early-19th-century cohorts from Sart (Alter, Dribe & Van Poppel 2007) and the Antwerp region (Donrovich, Puschmann & Matthijs 2014) found non-significant increases in later-life expectancy. Kannisto (2001) showed that the mode in later-life mortality increased for female cohorts from England, Finland, the Netherlands, and Switzerland. Moreover, the maximum age at death most likely also increased in these countries, as the maximum age at death increased linearly for the Swiss 1821-1888 cohort (Robine & Paccaud 2005). Furthermore, Caselli, Peracchi, Barbi & Lipsi (2003) found that the percentage of men and women living to be 70, 80, and 90 years old grew linearly for the 1861-1901 cohort. This suggests that the universal increases in later-life expectancy and longevity in Western Europe had already occurred for cohorts that were born in the early 19th century, and possibly earlier.

A beginning to human lifespan improvements is hard to pinpoint, as data on 18th-century cohorts is only available for French Québec, the settler population of South Africa, and Northern Finland. Helle, Lummaa and Jokela (2005) found no trend in life expectancy at age 45 for 1769-1839 cohorts from northern Finland, but it is doubtful that this region best represents the general population of Western Europe. Increases in later-life expectancy were not found for the 1680-1750 cohorts from Québec (Gagnon & Mazan 2009) or pre-1750 cohorts from South Africa (Cilliers & Fourie 2012). Yet, late-18th-century cohorts from South Africa seemed to be the first that started to grow older, indicating that, just like in Sweden, the longevity revolution already started in the early 19th century. These improvements in lifespan for pre-19th-century cohorts occurred well before improvements in preventive medicine, public health and dietary knowledge took force, which raises a lot of theoretical questions as for whom and as to why health was improving in the 19th century.

3 In line with results from the Human Mortality Database, the oldest old started to live longer halfway during the 19th- century in Sardinia (Salinari & Ruiu 2015), and the settler colonies of South Africa (Cilliers & Fourie 2012) and Utah (Temby & Smith 2014). Similarly, increases in later-life expectancy were found for eighteen Italian regions (Caselli et al. 2003; Salinari & Ruiu 2015), southern Sweden (Bengtsson & Broström 2009), Switzerland (Kannisto 2001; Robine & Paccaud 2005), and Utah (Lindahl-Jacobsen et al. 2013; Smith et al. 2009), although the trend was less clear for three Dutch provinces (Alter, Dribe & Van Poppel 2007). This overlap between the large-scale datasets and smaller-scale historical demographic studies shows that smaller populations can be used to estimate changes in longevity and later-life expectancy over time.

Figure 1. Life expectancy at age 50 and life expectancy for the top 1 survivors per cohort, by country



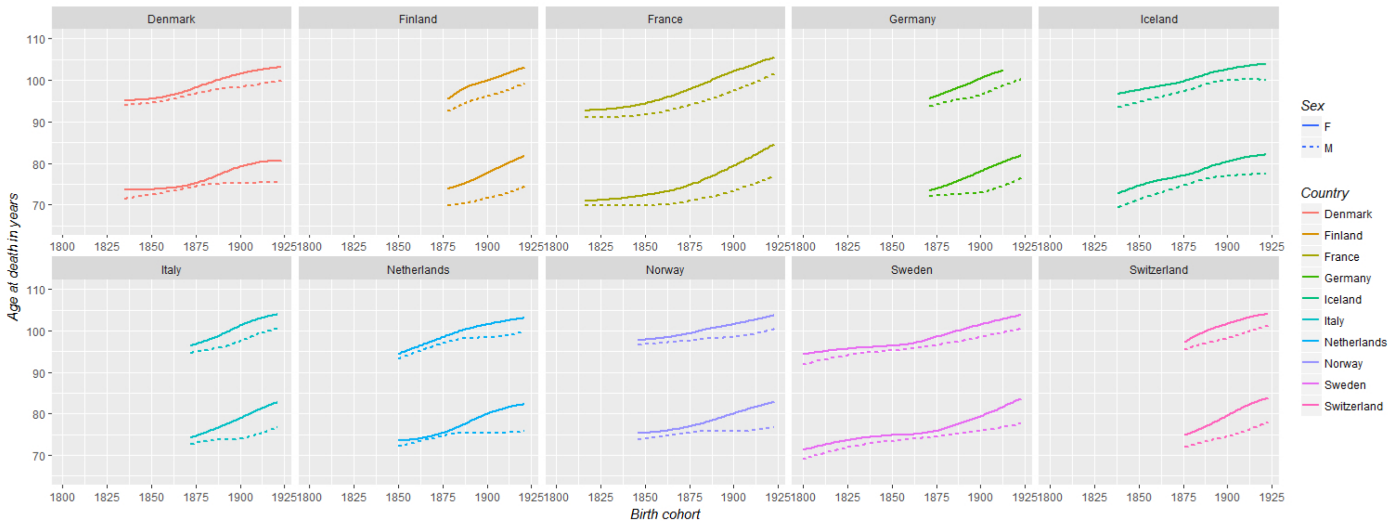
2.3 SEX DIFFERENCES IN LATER-LIFE MORTALITY AND LONGEVITY

Increases in life expectancy at age 50 and for the top 1% differed dramatically between the sexes. Nowadays, women live on average four to six years longer than men in modern populations (WHO 2016). However, as shown in Figure 2, differences between men and women in later-life expectancy and longevity radically increased for the 1850-1923 cohorts. Within the observed period, men attained only between 3.2 to 7.5 extra years, whereas women grew between 6.9 to 12.0 years older: a difference of 3.6 years. This development is most likely rooted in behavioral differences between the sexes, as the top male survivors were much more similar to their female counterparts than the average male population. The oldest women lived between 6.5 to 10.6 years longer in 1923 than in 1850, whereas men lived between 4.8 to 7.7 years longer. As a result, the difference in male and female longevity increased only 1.2 years, which shows how important it is to distinguish between male and female survival, as well as between exceptional and average survival in later life.

Reconstructions of pre-1850 cohorts reveal that sex differences in later-life expectancy were also quite small. Statistics on Sweden show that the difference between the oldest male and female cohort members was very stable at 1.5 years for all cohorts born between 1760 and 1890 (Wilmoth 2000). Similarly, differences between the oldest members of both sexes grew only marginally, from 0.5 to 1 year, between the 1776 and 1840 cohorts from Switzerland, after which the difference grew a bit more rapidly between 1840 and 1890 (Robine & Paccaud 2005). Yet, there is little evidence of a gender gap in later-life mortality. No difference existed in the life expectancy at age 55 for cohorts from late-18th-century Southern Sweden (Campbell et al. 2004). In Tuscan Casalguidi, women from the 1815-1859 cohort lived on average 1.5 years longer, whereas no gender gap was found for the 1800-1883 cohort Madregolo in Emilia (Campbell et al. 2004). In Belgium, Campbell et al. (2004) find little difference between male and female lifespan at age 55 for 19th-century cohorts in Belgian Sart, whereas Donrovich, Puschmann and Matthijs (2014) find that mortality is higher among men in the Antwerp region. Karlsson (2016) found, however, that a gender gap of 6.5 years in life expectancy at age 50 disappeared in Sápmi in the first half of the 19th century. Generally, environmental conditions and social factors affected to what extent women were able to express their genetic potential, especially before the 1860s.

The relatively stable sex differences in longevity, but growing differences in later-life mortality during the late 19th century, demonstrate why the study of non-genetic factors is so important. Unhealthy behavior, living in an unhealthy environment or lacking the right resources can easily overshadow one's genetic potential. Women might have always had the potential to outlive their male counterparts, but on average women who were born in the first half of the 19th century did not do so. To a large extent, environmental conditions and social factors affected to what extent women were able to express their genetic potential. Individual chances for a long life depend thus not only on individual characteristics, but also on gendered behavior. To understand why mankind has lengthened its lifespan over the past two centuries, and could further unlock its potential in the future, non-genetic factors should be studied from a gender perspective.

Figure 2. Sex differences in life expectancy at age 50 and life expectancy for the top 1 survivors per cohort, by country and sex



2.4 DETERMINANTS OF LATER-LIFE EXPECTANCY AND LONGEVITY

The temporal variety in later-life mortality and longevity over the past 200 years shows that genes are not destiny. Recently, multiple researchers have started to use microdata to discover the drivers of the longevity revolution. By determining whether certain population members had a higher life expectancy at age 50 or were more likely to be longevous, they are unravelling the mechanisms that triggered improvements in human survival. Most of these studies are fascinating natural experiments that cannot be conducted on contemporary populations, as living environments, households, kinship networks, socioeconomic structures, and lifestyles have changed dramatically over the centuries. By gauging which of the changes in these social structures affected human survival in later life, a framework is being built that not only determines the reasons for improved human survival, but also gives hints as to how human lives can be lengthened as much as possible.

2.5 EARLY-LIFE EXPOSURE TO ENVIRONMENTAL EFFECTS

One of the most prominent improvements in the environmental conditions over the past 200 years is the decreased exposure to epidemics and famines. Already in 2000, researchers from Lund University showed the effects of exposure to infectious diseases in early life on later-life mortality. In their study on the 1766-1839 cohorts from five parishes in Scania, Bengtsson and Lindström linked the crude death rate in an individual's birth year to lower rates of survival between ages 55 and 80. This effect was caused by infectious disease in the first year of life (Bengtsson & Lindström 2003), and affected men more strongly as they were impacted more by the whooping cough (Quaranta 2013). Outside the Scania region, the negative effect of early-life exposure to epidemics on later-life survival has yet to be established. For the same observation period, Donrovich, Puschmann, and Matthijs (2014) studied whether exposure to major outbreaks of cholera, malaria, measles, smallpox, or typhus during the first year of life affected mortality past age 50, and found that exposure in fact increased later-life expectancy. Gagnon and Mazan (2009), on the other hand, used the exact same measurement as the researchers from Lund, but in a different period, and found that infant mortality during the first life year had no effect on life expectancy at age 50 for the 1680-1750 Québec cohort. Neither of these studies applied the study design that was used to study the Scania population. Therefore, replications of the Lund studies are still necessary to determine whether epidemics had a scarring effect outside southern Sweden.

The relationship between famine and later-life mortality is less well established. Studies on the effects of food prices at birth, due to bad harvests, on later-life mortality have found no scarring effect (Bengtsson & Broström 2009; Bengtsson & Lindström 2000, 2003; Campbell et al. 2004; Gagnon & Mazan 2009; Quaranta 2013; Tsuya, Nystedt, Manfredini, Neven & Campbell 2004). However, this does not mean that in utero and perinatal exposure to nutritional shocks did not influence later-life mortality. These studies have been conducted on three 19th-century famines: the Dutch potato famine of 1846-1847, the

1855-1856 famine in Utah, and the 1866-1868 Finnish famine. The study on the Dutch potato famine shows that men who experienced intrauterine exposure to the famine had a lower life expectancy at age 50 (Lindeboom, Portrait & Van den Berg 2010). Hanson & Smith (2013), on the other hand, found little evidence for this claim in Utah, whereas research on the Finnish food crisis (Doblhammer, Van den Berg & Lumey 2013; Kannisto, Christensen & Vaupel 1997) showed that intrauterine famine affected later-life mortality only after increased variation within the male famine cohorts was taken into account. At first glance there seems, thus, no relation between early-life exposure to famine and later-life mortality.

The contradictory results from the different studies are strongly related to the applied research designs. The study on the Dutch potato famine only shows the bivariate relationship between famine and later-life expectancy, as the multivariate models contain a fatal misspecification.[4] As soon as background characteristics were taken into account, Kannisto, Christensen, and Vaupel (1997) found no effect of the famine at all, whereas Hanson and Smith (2013) found a weak positive effect for the female spring cohort of 1856 on later-life survival that was most likely caused by multiple testing. It thus seemed that perinatal famine had no effect on later-life mortality. However, in a restudy of the 1866-1868 Finnish famine, Doblhammer, Van den Berg, and Lumey (2013) found that famines could have a scarring effect. After controlling for frailty, male life expectancy at age 60 turned out to be lower in the three cohorts that were born during the famine. This effect was previously hidden by increased variation within male mortality. The variation in female mortality, on the other hand, was barely affected by the famine, which could explain why female life expectancy was not affected by the famine. But the authors do not address the question of why the variation in later-life expectancy increased. Most likely, the scarring effect of the Finnish famine relies on a characteristic that still needs to be found. Future studies should therefore be focused on identifying the variables that determine the scarring effect of famines, for example by studying whether the scarring effect of a famine clusters within specific families.

2.6 LATER-LIFE EXPOSURE TO ENVIRONMENTAL EFFECTS

Besides the early-life environment, later-life environmental characteristics also play an important role in later-life mortality. Within the general literature on mortality, authors have hinted at the possible effects of urbanization, industrialization, geographic isolation, disease environment, and agricultural tradition (see e.g. Devos & Van Rossem 2015; Van Poppel 1992). Nevertheless, the influence of the later-life living environment on later-life mortality has received little attention. So far, three studies have analyzed the relationship between urbanization and later-life mortality. The results from these studies were mixed. A 2009 study found that both male and female city dwellers from the 1680-1750 cohort in the Saint Lawrence Valley in Québec lived shorter lives than the rural population at age 50, regardless of whether these people were born in a rural or urban environment (Gagnon & Mazan 2009). The same author, however, found that urban residence coincided with a higher life expectancy at age 50 for the 1809-1869 cohort from neighboring Saguenay-Lac-St-Jean, Québec (Gagnon et al. 2009). Temby and Smith (2014) found the same result for the 1840-1909 Utahn male cohort when they compared urban and rural counties in Utah. Still it is hard to interpret these contradictory results. All studies measured urbanization dichotomously, i.e. as urban/non-urban. This creates a concrete cut-off point, even though incremental differences in city size might have been more important than the dichotomy between cities and rural towns. As a result, it is uncertain whether the different findings indicate that the relationship between later-life mortality and urbanization was varied by time and place, or resulted from imprecise measurements.

To allow for a more in-depth study of long-lived individuals, Poulain, Herm, and Pes (2013) have been identifying regions with an unusually high number of centenarians, so-called Blue Zones. Hitherto, four areas with an unusually high proportion of centenarians have been observed: east Sardinia, Okinawa, the Nicoya peninsula in northwest Costa Rica, and the Greek island of Ikaria. By comparing these long-lived regions, insight should be generated into the ideal living conditions for people who were born at the turn of the 20th century. A comparison between the Sardinian municipalities showed that in isolated regions longevity depended on pastoralism and, according to a 1930 health survey, a better quality diet. According to the authors this shows that a traditional lifestyle with continuous physical activity, intensive family and community support, and local food production produced many long-lived individuals (Poulain, Harm & Pes 2013). Yet, these findings are open to interpretation, as they are based on indirect measurements and aggregated data.

4 The independent variables interacted with the dependent variable.

It cannot be concluded that factors identified by Blue Zones research necessarily improved an individual's chances to live exceptionally long lives until a more systematic comparison between regions has been conducted. The study of these four regions can give indications of environmental factors that might have encouraged extreme longevity on the verge of the 20th century. But it might also falsely dismiss environmental characteristics that decrease mortality in later life. Since the number of regions that is being compared is so low, it is hard to discern a pattern. With only five cases to study, similarities easily appear meaningful, even though they may be based on pure chance. Conversely, important determinants of longevity can be missed, as a single exception to the rule carries a lot of weight. Thus, the research on Blue Zones can produce leads for further research, but it does not necessarily identify effects that are also applicable to other situations. Multiple researchers have therefore been enriching large-scale demographic data with contextual factors (Hanson, Smith & Mineau 2015; Hedefalk, Harrie & Svensson 2015) to test hypotheses on the effect of agricultural tradition, altitude, disease environment, geographic isolation, industrialization, urbanization, and water quality. These datasets that combine demographic and environmental data will most likely shed light on to what extent and how the living environment in later life affected mortality and longevity.

Table 1 *Overview of studies on determinants of later-life mortality and longevity for the late-18th and 19th century environment*

Determinant	Population	Cohort	Definition	Variable	Effect	Authors
Disease environment	Scania	1711-1839	survival 55-80	main variable	-	Bengtsson & Lindström (2000; 2003)
		1663-1848	survival 55-70 (m) survival 55-70 (f)	main variable	-	Quaranta (2013)
	Antwerp region	1800-1859	LE50	covariate	none	Donrovich, Puschmann & Matthijs (2014)
	Quebec	1680-1750	LE50 (m) LE50 (f)	main variable	none	Gagnon & Mazan (2009)
Food prices	Casalguidi Madregolo Sart Scania	1815-1859 1800-1883 1757-1845 1711-1810	LE55	bivariate	none none none none	Campbell et al. (2004); Tsuya et al. (2004)
	Quebec	1680-1750	LE50 (m) LE50 (f)	main variable	none	Gagnon & Mazan (2009)
	Scania	1711-1839	survival 55-80	covariate	none	Bengtsson & Lindström (2000; 2003)
		1733-1844	survival 50-80	covariate	none	Bengtsson & Broström, (2009)
		1663-1848	survival 55-70 (m) survival 55-70 (f)	main variable	- none	Quaranta (2013)
Famine	Finland	1866-1868	LE60/80 (m) LE60/80 (f)	main variable	none	Kannisto, Christensen & Vaupel (1997)
			LE60 (m) LE60 (f)	main variable	-	Doblhammer, Van den Berg & Lumey (2010)
	Netherlands	1846-1847	LE50	bivariate	+	Lindeboom, Portrait & Van den Berg (2010)
	Utah	1855-1856	LE50 (m) LE50 (f)	main variable	none	Hanson & Smith (2013)
Urbanization	Quebec	1680-1750	LE50 (m) LE50 (f)	covariate	-	Gagnon & Mazan (2009)
	Saguenay-Lac-Saint-Jean	1809-1869	LE60 (m)	covariate	+	Gagnon et al. (2009)
	Utah	1840-1909	LE40 (m) Top 1% (m)	covariate	+	Temby & Smith (2014)

2.7 HOUSEHOLD COMPOSITION

Later-life mortality depended not only on the living environment but also on the availability of socioeconomic resources. The attainment of these resources depended heavily on household composition, as many resources were shared more or less equally based on gender and age due to hierarchical systems of redistribution in the household.

Seniority in the household was a significant indicator of later-life mortality. Being firstborn had a negative effect for women from the 1855-1871 Utahn cohort (Hanson & Smith 2013), whereas men were unaffected. Both sexes, however, suffered from being born later in the birth order. In a study on the Antwerp region, Donrovich, Puschmann and Matthijs (2014) showed that the negative effect of birth order on later-life mortality depended on the number of older brothers that individuals had. Most likely this resulted from the redistribution of resources within the household, as not only older brothers, but also household heads, had lower mortality than other household members. Research on the 1757-1845 cohort from Scania showed household heads had a better life expectancy at age 60 between 1895 and 1968, but not between 1815 and 1894 (Bengtsson & Dribe 2011). The distribution of resources in both early and later life thus impacted later-life mortality.

Table 2 *Overview of studies on determinants of later-life mortality and longevity for the late-18th and 19th-century, household composition*

Determinant	Population	Cohort	Definition	Variable	Effect	Authors
Firstborn	Antwerp region	1800-1859	LE50	main variable	+	Donrovich, Puschmann & Matthijs (2014)
	Utah	1855-1871	LE50 (m) LE50 (f)	covariate	none -	Hanson & Smith (2013)
Household head	Scania	1755-1840 1841-1900	LE60	covariate	none +	Bengtsson & Dribe (2011)
Household size	Casalguidi Madregolo Sart Scania	1815-1859 1800-1883 1757-1845 1711-1810	LE55	bivariate	none none none -	Lee et al. (2004); Tsuya et al. (2004); Breschi et al. (2004)
*Offspring**	Northern Finland	1679-1839	-/+ LE50	main variable	none	Helle, Lummaa & Jokela (2005)
	rural Finland	1700-1899	survival 50-79 (f) survival 50-79 (m) LE80 (f) LE80 (m)	main variable	none	Korpelainen (2000)
	Ostfriesland	1720-1870	1670-1800	main variable	none	Lycett, Dunbar & Voland (2000)
	Utah	1860-1895	LE60	main variable	+	Smith, Mineau & Bean (2002)

* See also reviews by Helle, Lumma & Jokela (2005), Hurt, Ronsmans & Thomas (2006) and Le Bourg (2007)

The number of adult household members seemed to be of less importance. A comparative study applying descriptive data found that whether individuals suffered from living in a multigenerational household differed widely between villages in Northern Italy, Belgium, and southern Sweden. After age 55, there was no relationship between the number of adult household members and mortality for Casalguidi and Madregolo in Northern Italy. In Belgian Sart, however, having extra adult female household members increased life expectancy at age 55, whereas in Swedish Scania having multiple adult male household members decreased life expectancy at age 55 (Breschi, Derosas, Manfredini & Lee 2004; Lee et al. 2004; Tsuya et al. 2004). This indicates that the effect of adding an extra household member to a household is largely dependent on local family systems. As a result, the effect of adding an extra member to a household can only be understood if regions with different systems of intergenerational care are studied. Nevertheless, these results should be interpreted with caution, because they were retrieved from bivariate statistics on small samples and are not corrected for similarities between household members.

There might be an effect of the number of offspring on maternal survival, although this effect is also estimated to be small. Studies conducted for the 1990s generally found that the bivariate relationship between the number of children and later-life mortality was U-shaped, with the lowest mortality for women who have 2 to 3 children (Hurt, Ronsmans & Thomas 2006). However, a new wave of studies – inspired by Westendorp and Kirkwood (1998) – that incorporated multiple variables has not been able to find a clear effect (Le Bourg 2007). For cohorts from 1679-1839 Sami parishes (Helle, Lummaa & Jokela 2005), 1700-1899 rural Finland (Korpelainen 2000), and 1720-1870 Ostfriesland (Lycett, Dunbar & Voland 2000) no effect was found. In 1860-1895 Utahn cohorts, a negative relationship was found (Smith, Mineau & Bean 2002), whereas in immigrant and native 1608-1700 cohorts in Québec a positive relationship was found (Le Bourg, Thon, Légaré, Desjardins & Charbonneau 1993). Although an effect of sibship size on maternal later-life mortality cannot be ruled out, most likely it is so small that it is easily subdued by other non-genetic factors. Therefore, the relationship can only be tested if researchers feel that they can sufficiently control for non-genetic effects.

2.8 SOCIAL SUPPORT

Later-life mortality was not only the result of kin rivalry, as family members also supported one another. Multiple studies, for example, have shown that men were dependent on their wives for survival in later life. In France, Utah, the Belgian towns of Antwerp and Sart, and Scania, male singles had a lower later-life expectancy (Bengtsson & Dribe 2011; Donrovich, Puschmann & Matthijs 2014; Gellatly & Störmer 2015; Hanson & Smith 2013). Similarly, widowerhood negatively affected male chances of a long life. The death of a spouse was detrimental to male survival in later life in Utah (Smith, Mineau, Garibotti & Kerber 2009), Scania, and Sart (Alter, Dribe & Van Poppel 2007; Lee et al. 2004; Tsuya et al. 2004). However, this effect was absent in the Dutch provinces of Friesland, Utrecht, and Zeeland (Alter, Dribe & Van Poppel 2007) and the northern Italian towns Casalguidi, Madregolo and Venice (Breschi et al. 2004; Lee et al. 2004; Tsuya et al. 2004).

Table 3 *Overview of studies on determinants of later-life mortality and longevity for the late-18th and 19th century, social support*

Determinant	Population	Cohort	Definition	Variable	Effect	Authors
Widowhood	France	1748-1851	Survival per year	bivariate	-	Gellatly & Störmer (2015)
	Scania	1757-1845	LE60	covariate	-	Bengtsson & Dribe (2011)
	Utah	1855-1856	LE50 (m) LE50 (f)	covariate	-	Hanson & Smith (2013)
Widowerhood	Sart Netherlands Scania	1762-1849 1800-1955 1766-1845	LE50	main variable	- none -	Alter, Dribe & Van Poppel (2007)
	Casalguidi Madregolo Venice	1815-1859 1800-1883 1800-1820	survival 55-74	covariate	none	Breschi et al. (2004)
	Utah	1850-1900	LE50	covariate	-	Smith et al. (2009)
Elderly support	Antwerp region	1800-1859	LE50	covariate	+	Donrovich, Puschmann & Matthijs (2014)
	Quebec	1680-1750	LE50	covariate	+	Gagnon & Mazan (2009)
	Netherlands	1800-1955	LE50	covariate	+	Alter, Dribe & Van Poppel (2007)
	Utah	1855-1856	LE50	covariate	-	Hanson & Smith (2013)
Sibling support	Antwerp region	1800-1859	LE50	main variable	+	Donrovich, Puschmann & Matthijs (2014)
	Quebec	1680-1750	LE50 (m) LE50 (f)	covariate	+	Gagnon & Mazan (2009)

How widowhood affected later-life mortality seems to have depended on the support that parents received from their children. In Friesland, Utrecht, and Zeeland (Alter, Dribe & Van Poppel 2007) the impact of widowhood on later-life mortality was determined by the number of children a woman had. Similarly, mothers from the 1680-1750 cohort in Québec profited from the number of children that reached age 50 (Gagnon & Mazan 2009). In the 1855-1856 Utah cohort, childless men also tended to live shorter lives. However, such an effect was not present for childless women in Utah (Hanson & Smith 2013), and for childless women from the 1800-1860 cohort in the Antwerp region there was even a positive effect on later-life expectancy. This indicates that children were needed to support their parents in their old age.

Whether in addition to parents and offspring, siblings were also sources of support in later life is less well known. However, in an in-depth study on the Belgian Antwerp region, Donrovich, Puschmann and Matthijs (2014) tested whether having living younger sisters at age 50 affected men and women differently. Women profited from having younger sisters in later life, as they increased life expectancy at age 50, whereas men's mortality in later life was not affected by the number of younger sisters. This marks a first step in uncovering the effect of social support on survival in later life. Future studies would do well to focus on regional differences in household systems and take the relationships within families into account.

2.9 SOCIOECONOMIC POSITION

The total level of familial resources in 19th-century cohorts was of less importance than the distribution of resources within the household. In most regions differences in socioeconomic position were found to have no or marginal impact on later-life mortality, even though social class coding systems differed wildly. In a study on Dutch married women born between 1850 and 1889, few differences were found between wives of unskilled, semiskilled, non-manual, and supervisory workers or holders of no, small, and large properties (Alter, Dribe & Van Poppel 2007). In Scania, social power (SOCPO) at age 60 was unrelated to mortality after age 60 (Bengtsson & Dribe 2011) and, for the Antwerp region, Donrovich, Puschmann, and Matthijs (2014) found no effect of social class (HISCLASS 4) on mortality after age 50. There thus seems little evidence of a relationship between socioeconomic and later-life mortality for individuals who were born in the 19th century.

A positive effect of socioeconomic status (Nam-Powers) on later-life expectancy has been found consistently for the Utah population, however. Smith et al. (2009) found a strong negative relationship between socioeconomic status at death and later-life mortality for the 1850-1900 born Utah population. In an in-depth study on the relationship between familial longevity and a socioeconomic status, Temby and Smith (2014) found that a higher Nam-Powers score increased both the LE40 and the odds of belonging to the top 5% of survivors. The different results from the Utah studies could simply indicate that the Utah population is different from the other populations, or that the Nam-Powers index is a better measurement for socioeconomic position. However, it is more likely that a better measurement of intra-family effects influenced the results. All Utahn papers compared sibling pairs and thus controlled for familial clustering of socioeconomic positions. Future studies on later-life mortality should therefore control for the similarity between siblings in socioeconomic positions.

A lot of papers have also focused on the effects of landownership, as those with land were deemed food secure. Farmers from the late 19th century Utahn and Saguenay-Lac-Saint-Jean cohorts tended to live longer than non-farmers (Gagnon et al. 2009; Temby & Smith 2014). However, this effect was not present for early 19th-century cohorts from the Antwerp region, and children of farmers even had higher later-life mortality (Donrovich, Puschmann & Matthijs 2014). For 18th-century cohorts from southern Sweden there were no general differences between freeholders, tenants, crofters, and landless in later-life mortality. But, strong period effects show that freeholders, tenants, crofters, and the landless reacted differently to the challenges that occurred over time (Bengtsson & Broström 2009). A study on the Scanian 1766-1839 cohort, furthermore, showed farmers had higher mortality between age 55 and 80 and were less likely to die of old age – i.e. not of airborne or non-infectious diseases – than artisans and cottagers, but suffered less from fluctuations in food prices than cottagers (Bengtsson & Lindström 2000). Farmers were, in other words, subjected to different hardships than city dwellers. This shows that later-life survival was dependent on behavior within a historical context, which indicates that not only social class, but also occupation-associated behavior should be studied.

Table 4 *Overview of studies on determinants of later-life mortality and longevity for the late-18th and 19th century, socioeconomic position and behavior*

Determinant	Population	Cohort	Definition	Variable	Effect	Authors
Social class	Sart Netherlands Scania	1762-1849 1800-1955 1766-1845	LE50	covariate	none	Alter, Dribe & Van Poppel (2007)
	Scania	1757-1845	LE60	main variable	none	Bengtsson & Dribe (2011)
	Antwerp region	1800-1859	LE50	covariate	none	Donrovich, Puschmann & Matthijs (2014)
	Utah	1850-1900	LE50 (m) LE50 (f)	covariate	+	Smith et al. (2009)
	Utah	1840-1909	LE40 (m) Top 1% (m)	main variable	+	Temby & Smith (2014)
Behavior	Antwerp region	1800-1859	LE50	covariate	-	Donrovich, Puschmann & Matthijs (2014)
	Saguenay-Lac-Saint-Jean	1809-1869	LE60 (men)	main variable	+	Gagnon et al. (2009)
	Scania	1766-1839	survival 55-80	main variable	+	Bengtsson & Lindström (2000)
		1757-1845	LE60	main variable	+	Bengtsson & Dribe (2011)
	Utah	1850-1900	LE50 (m) LE50 (f)	covariate	+	Smith et al. (2009)
	Utah	1840-1909	LE40 (m) Top 1% (m)	main variable	+	Temby & Smith (2014)

2.10 BEHAVIOR

Of all the individual-level effects, behavior seems to have had the largest impact on later-life mortality. Information on the effects of 19th-century lifestyles on later-life mortality has recently become available through two landmark studies. These studies on the late 19th century Utahn and Sardinian populations are landmarks, as they show that the impact of behavior on later-life expectancy and longevity can still be studied through the use of natural experiments or detailed historical reports. By combining qualitative insight with precise testing of hypotheses, researchers in Utah showed that drinking and smoking can explain half of the gender gap in later-life expectancy that grew between men and women, and Pes et al. (2013) proved that healthy diets lengthen human lifespan.

Lindahl-Jacobsen et al. (2013) studied whether Mormon settlers in Utah fared better than their non-converted countrymen. The Church of Jesus Christ of Latter-day Saints (LDS) discourages drinking and smoking, which should result in lower later-life mortality. A comparison of the life expectancy at age 50 between Danes, Swedes, and Utahns from Danish or Swedish decent from the 1850-1910 cohort showed that the life expectancy at age 50 of Danes, Swedes, and non-LDS members in Utah did not differ. Active members of the Mormon Church, however, had a significantly higher life expectancy at age 50 than inactive and non-LDS members, and, as a later study showed, a higher chance of belonging to the oldest 5% of the Utah population (Temby & Smith 2014). Men profited most from active LDS membership, as active members of the LDS lived on average two to four years longer than inactive or non-members. For women the benefits of LDS membership were much smaller, as differences between non-members and members were limited to one year. This indicates that the sex differences in later-life mortality that grew in the latter part of the 19th century are for about fifty percent attributable to smoking and drinking, and for the rest rooted in other trends.

Pes et al. (2013) studied the influence of lifestyle on the chance of becoming a centenarian on a municipal level for men. Municipal data was gathered from a 1934 questionnaire on diet, occupation, and physical condition, the 1929 agrarian census, and contemporary geographical data. Male inhabitants from regions with high terrain slopes had a better chance of becoming a centenarian. Although these men were about as tall as other Sardinians, their chest circumference was a bit larger, which indicates a better physical condition. Besides living in a mountainous region, two other explanations were found for this result. First, inhabitants of these municipalities had a healthier diet and consumed less wine and more barley. There was, however, no effect from meat, wheat, nut, or cheese consumption. Second, male centenarians were more common in municipalities with more pastoralists. According to the authors, pastoralists had an active lifestyle with physically less intensive, but more continuous labor than farming. Moreover, they kept working until relatively high ages. Good nutrition and prolonged physical activity might thus be very beneficial for survival, yet these results are retrieved from indirect measurements and need to be replicated in other regions.

Table 5 *Overview of studies on determinants of later-life mortality and longevity for the late-18th and 19th century, behavior*

Determinant	Population	Cohort	Definition	Gender gap	Effect	Authors
Alcohol & tobacco consumption	Utah	1850-1910	LE50 (m) LE50 (f)	main variable	-	Lindahl-Jacobsen et al. (2013)
	Utah	1840-1909	LE40 (m) Top 1% (m)	covariate	-	Temby & Smith (2014)
Diet	Sardinia	1900-1913	male centenarian	main variable	+	Pes et al. (2013)
Physical activity	Sardinia	1900-1913	male centenarian	main variable	+	Pes et al. (2013)

3 CONCLUSION

Due to the improvement of living environments, the eldest in society were already growing older before the 20th century. This is interesting as improvements in later-life mortality and longevity occurred for all 19th-century cohorts under study. Moreover, data on Sweden even shows that the maximum human lifespan was already lengthening for 18th-century cohorts. Consequently, the moment when later-life expectancy and longevity started increasing is unknown, which has major implications on how we view the demographic and epidemiological transition. Future research should therefore reconsider existing explanations for improvements in survival during the 19th century and reconstruct when and why the lives of the oldest were lengthening. This search will shed a new light on the demographic and epidemiological transition, and could force us to rethink these frameworks altogether.

The necessity to rethink explanations for the longevity revolution is further stressed by gender inequalities in later-life expectancy and longevity. The data show that differences in longevity between men and women have always existed and are more or less stable over time. However, difference in the life expectancy at age 50 changed strongly over time and were not uniform between countries. Inequalities in average male and female survival started growing from the 1870s onwards, whereas they were small to non-existent for cohorts born earlier in the 19th century. This indicates that the adverse circumstances for women were quite strong during the 19th century, and that the severity of these circumstances differed greatly between communities. Comparative studies should therefore be able to produce new insights into how gender inequality could negatively affect later-life mortality.

Demographic studies have shown that later-life expectancy is dependent on a wide array of non-genetic factors. In the research on historical longevity, a lot of ground has already been covered. First results from a wide range of studies have laid the groundwork for a theoretical framework on longevity. Later-life mortality and longevity were to some extent determined by the disease environment, availability of food, and local diets. Within these communities, social support from spouses and kin in later life was an important source for living a long life, whereas the effects of socioeconomic position had a smaller impact. But the most important predictor of later-life expectancy and longevity were behavioral characteristics – such as smoking, drinking, exposure to infectious disease, or maintained physical activity in later life – that were strongly rooted in occupational, religious, and local practices. Together, these environmental, familial, and individual factors form a theoretical framework that can start to explain why human lives had lengthened for cohorts from the 19th century. By focusing on this framework and making comparisons between regions for specific timeframes, reasons for increases in later-life expectancy and longevity will be revealed.

Cautionary notes need to be made on the methodological state of the field, however. Studies on 19th-century cohorts tend to favor short descriptions of the data and in many publications the inescapable problem of missing data is not even mentioned. This is surprising, as the importance of data quality can hardly be understated for studying mortality in later life. The long observation period allows for migration in the populations under study. Moreover, even stayers might have been excluded from analyses, as information on certain indicators was missing, for example occupation. This hampers the external validity of the data if specific groups are excluded from the analyses. Therefore, any paper on later-life mortality and longevity for 19th-century cohorts would do well to discuss these blind spots in the data and analyses.

Second, few studies take clustering of later-life mortality and longevity into account. Yet, individual chances for a long life depend on living environment, household composition, familial support, socioeconomic status, and lifestyle, which are not randomly distributed among individuals. Moreover, studies of modern populations have also shown that longevity is in many cases not an isolated hit, but clustered within a limited number of families. Long-lived individuals and their offspring age more healthily than other individuals (Ash et al. 2015; Atzmon et al. 2004; Christensen ,McGue, Petersen, Jeune & Vaupel 2008; Newman et al. 2011; Slagboom et al. 2011; Terry et al. 2004; Terry et al. 2008). Hence, the clustering of non-genetic determinants of later-life mortality and longevity likely has distorted existing research findings. To understand how specific families encouraged longer lives, the relationship between these factors and mortality in later life needs to be studied further.

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Appendix A Overview of studies into the development of later-life mortality and longevity for late-18th- and 19th-century cohorts

Country	Population	Cohort	Definition	Trend	Authors
Belgium	Antwerp region	1800-1859	LE50	n.s. (+)	Donrovich, Puschmann & Matthijs (2014)
	Sart	1812-1849	LE50	n.s. (+)	Alter, Dribe & Van Poppel (2007)
Canada	Quebec	1680-1750	LE50	none	Gagnon & Mazan (2009)
Denmark	Denmark	1850-1910	LE50	+	Lindahl-Jacobsen et al. (2013)
England	England (f)	1741-1890	Mode	+	Kannisto (2001)
Finland	Sami parishes (women)	1679-1839	LE45	none	Helle, Lummaa & Jokela (2005)
	Finland (f)	1751-1895	mode	+	Kannisto (2001)
Italy	Villagrande Strisaili (Sardinia)	1866-1910	LE80	+	Salinari & Ruiu (2015)
	Italy (f) Italy (m)	1861-1901	% surviving to 70/80/90	++ +	Caselli et al. (2003)
Netherlands	Friesland, Utrecht, Zeeland	1850-1889	LE50	n.s. (+)	Alter, Dribe & Van Poppel (2007)
	Netherlands (f)	1750-1895	mode	+	Kannisto (2001)
South Africa	Settler population	1600-1750	LE50 top 5%	none none	Cilliers & Fourie (2012)
		1751-1900	LE50 top 5%	+ +	
Sweden	Sápmi (Sami f) Sápmi (Sami m)	1770-1850	LE50 / LE80	- none	Karlsson (2016)
	Scania (f)	1766-1845	LE50	+	Alter, Dribe & Van Poppel (2007)
	Scania	1733-1844	survival 50-80	+	Bengtsson & Broström, (2009)
	Scania	1711-1839	survival 55-80	+	Bengtsson & Lindström (2000; 2003)
	Sweden	1850-1910	LE50	+	Lindahl-Jacobsen et al. (2013)
	Sweden	1760-1865 1865-1890	oldest cohort member	+ ++	Wilmoth (2000)
Switzerland	Switzerland (f)	1776-1893	Mode	+	Kannisto (2001)
	Switzerland (f) Switzerland (m)	1776-1820	oldest cohort member	none none	Robine & Paccaud (2005)
	Switzerland (f) Switzerland (m)	1821-1888	oldest cohort member	+ +	
USA	Utah	1850-1900	LE50	+	Smith et al. (2009)
	Utah	1840-1909	top 5%	+	Temby & Smith (2014)
	USA (f)	1831-1895	mode	+	Kannisto (2001)

Appendix B Overview of studies into gender gaps in later-life mortality and longevity for the late-18th and 19th-century cohorts

Country	Population	Cohort	Definition	Gender gap	Authors
Belgium	Antwerp region	1800-1859	LE50	+	Donrovich, Puschmann & Matthijs (2014)
	Sart	1812-1849	LE50	none	Alter, Dribe & Van Poppel (2007)
Denmark	Denmark	1850-1880 1890 1900	LE50	2 year 2.5 years 5 years	Lindahl-Jacobsen et al. (2013)
Italy	Casalguidi (Tuscany)	1815-1859	LE55	1.5 years	Campbell et al. (2004)
	Madregolo (Emilia)	1800-1883	LE55	none	Campbell et al. (2004)
	Villagrande Strisaili (Sardinia)	1866-1910	LE80	+	Salinari & Ruiu (2015)
Sweden	Sápmi (Sami)	1800 1850	LE50	5.5 years none	Karlsson (2016)
	Scania	1711-1810	LE55	none	Campbell et al. (2004)
	Sweden	1850-1880 1890 1900	LE50	2.5 year 4 years 5 years	Lindahl-Jacobsen et al. (2013)
	Sweden	1760-1890	oldest cohort member	1.5 years	Wilmoth (2000)
Switzerland	Switzerland	1776 1840 1890	oldest cohort member	0.5 years 1 year 2 years	Robine & Paccaud (2005)
USA	Utah	1850-1865 1880 1900	LE50	1 year 3 years 6 years	Lindahl-Jacobsen et al. (2013)