Modal Age at Death: Mortality Trends in England and Wales 1841–2010

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Abstract

Mortality in England and Wales has changed dramatically since 1841. Recent studies of the late modal age at death show that some low mortality countries are demonstrating a shifting mortality scenario following overall mortality compression, which dominated from 1900. England and Wales have appeared briefly in these works but are not the sole focus. This report will focus solely on males and females in England and Wales by smoothing, using a nonparametric method, mortality rates used to construct period life tables from which modal age at death can be extracted for each year from 1841 to 2010. Mortality compression around and above the mode are also measured.

The modal age at death increased by 14.59 years for males and 11.37 years for females between 1841 and 2010. Mortality in England and Wales has compressed into a shorter age interval; mortality above the mode has also compressed but is now stagnating for females. Evidence is not strong enough to suggest England and Wales are demonstrating a shifting mortality scenario. In fact, females may be in an "intermediate situation" characteristic of moving into the shifting mortality scenario.

This report recommends modal age at death should be used in combination with other measures of life duration in order to draw a comprehensive picture of mortality changes in low mortality countries. A further recommendation is for the Office for National Statistics (ONS) to use this technique to gain a greater understanding of the mortality and longevity they project for the future for England, Wales and the rest of the United Kingdom.

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1 Introduction

1.1 Setting the scene

Mortality in England and Wales has changed dramatically since 1841, but the way it is measured has remained consistent. Life expectancy (L.E.), the mean age at death according to a hypothetical population, remains the leading indicator of health, mortality and population aging in England and Wales. Because of improvements in mortality, L.E. increases and more people are living longer. The large amount of people reaching age 70, 80 or 90 contributes to an aging population, which in turn raises policy and planning concerns for pensions and health and social care provisions. As mortality continues to improve at the oldest ages, it becomes more important to understand how long people are going to live.

As the age pattern of mortality—the pattern created by the numbers dying at each age—moves or shifts to older ages, it becomes more evident we are moving away from a compression of overall mortality (Fries 1980). The compression is where deaths occur in a more concentrated age range; as we move away from this, a new mortality regime emerges. As the age-at-death distribution has changed shape, it has become apparent that the average mean measure of the duration of life (L.E.) has become less meaningful. This is especially so in countries with low mortality such as England and Wales. To understand recent changes in mortality patterns, it has become appropriate to use a different measure of the average life duration more suited to the distribution of deaths we see today.

This project has used life tables[1] to establish the modal age at death (mode), the age at which most deaths in the population occur, to help understand the shifts in mortality between 1841 and 2010 in England and Wales. It has also presented the future possible pattern of mortality know as the shifting mortality scenario. This scenario is a more recent phenomenon used by demographers to explain the changes (1970 onward) in the age-at-death distribution (Kannisto 1996). The project has used four research questions to understand mortality trends in England and Wales between 1841 and 2010. Methodological tools such as the mode, standard deviation above and around the mode, median and the interquartile range have also been used to fully answer the research questions.

[1] Life tables are a demographic tool used to calculate hypothetical life expectancy based on deaths by single year of age and midyear population estimates (Rowland 2003).

1.2 Research questions

The following research questions have been answered.

1. How has the modal age at death in England and Wales changed over time?
2. How has the standard deviation (S.D.) of ages at death around and above the mode changed over time?
3. Is England and Wales demonstrating a shifting mortality scenario?
4. Is modal age at death a more appropriate measure than life expectancy for England and Wales?

These research questions have been designed so that trends in the modal age at death can be followed throughout the whole time period. The questions focus on the compression of mortality, as measured by the S.D., and the shifting mortality scenario, which is measured and monitored using S.D. above the mode (the methodology is discussed in greater detail in section 3). The final question is used to assess the evidence to the previous questions and to evaluate whether the modal age at death can tell us more about the longevity and mortality situation for England and Wales compared to life expectancy.

1.3 Why is understanding longevity important?

The work surrounding understanding patterns of mortality and longevity is important for numerous reasons. In England and Wales, the importance lies with the aging population and accurately preparing for the size and length of life for generations to come. It is evident that policies associated with aging are at the top of the government agenda in England and Wales (Pensions Act 2011; DWP 2013). Policy concerns include those surrounding pensions, retirement ages, older workers, well-being, and health and social care planning and provision. These topic areas have become more and more important because they are a great expense for the individual and the government, making it imperative to accurately predict life duration for future generations. Modal age at death is a possible predictor of life duration particularly suited to a low mortality country seeing improvements in mortality at the oldest ages. The benefits of using the mode are discussed in more detail in section 3.

There are also reasons for understanding that are important to government departments such as ONS, which this project is carried out on behalf of and in partnership with. ONS requires an accurate understanding of mortality and longevity to inform the mortality projection process for the National Population Projections, which then feed into policy decisions made by wider government. The issues ONS has to consider when projecting mortality levels include mortality at the oldest ages (90+), convergence and divergence of male and female mortality and expectation of life, and at what age to close off a life table.

Understanding mortality, especially at the oldest ages, will also continue to feed into the ongoing debate regarding the limit to life expectancy and for understanding the possibilities for the future (Oeppen and Vaupel 2002). Populations also have an ongoing need to monitor the health status of the population and to make comparisons with other countries to monitor improvements in health and mortality.

1.4 Current research on modal age at death

Modal age at death, the compression of mortality and the shifting mortality scenario have all featured in research, including Ouellette and Bourbeau (2011a), Thatcher et al. (2010), Canudas-Romo (2008) and Kannisto (2001). The emergence of work in this field has been recent and is associated with the slowing of compression of mortality and the improving mortality rates at the oldest ages. Work covers various low mortality countries including England and Wales and shows that within the demographic world this is a current topic, which then feeds into the social and political worlds. The details and the findings of selected studies are discussed in section 2.

1.5 Outline and findings of this report

This report takes the reader through the background of life expectancy as a measure of mortality, how this has changed in England and Wales, how we have reached low mortality and therefore how this generates the need for an alternative or additional measure of mortality. A review of selected research surrounding modal age at death in various countries follows. The data and methodology chosen for this project is described and justified in section 3, followed by the results, which are split into two parts. These sections focus on the research questions presented earlier and provide evidence to answer each question. The final sections discuss the results in terms of answering the research questions; it then draws on the conclusions to make suggestions for an aging population and the policy concerns associated with this.

This project, through this report, presents findings to show that modal age at death has increased in England and Wales by 11.37 years for females, to 88.53 years, and by 14.60 years, to 85.44 years, for males between 1841 and 2010. Deaths at the mode have become more common, with over 4 percent of female deaths occurring at the mode in 2010. Survival at all ages has improved for each year, demonstrating rectangularization of the survival curve; it is also evident there has been a reduction in the variability in the age at death in England and Wales, also known as a compression of mortality. This compression has more recently slowed. Negative correlation is therefore observed as the modal age at death increases and the variation of life spans decreases.

The findings also show that compression of mortality above the mode has occurred but at a much slower pace than overall compression, and is stagnating for females in England and Wales. Periods of stagnation are presented as evidence toward the shifting mortality scenario, particularly in the 1980s and 1990s for females. The findings also provide evidence for a possible shift in the mortality scenario for males in the 1980s, although the evidence is not strong enough to definitively say England and Wales is demonstrating a shifting mortality scenario. It is concluded that the mode should be used within a combination of measures of life span in future analysis. L.E. has become less informative for an aging population over time but it is still a universally understood measure. It is recommended that a combination of methods be considered, with the selection of the measure (mean, median or mode) to be made according to which measure is the most appropriate to the population age structure and age-at-death structure being studied.

1.6 Summary

Mortality and health in England and Wales is commonly measured through life expectancy; this project introduces modal age at death as an alternative measure of longevity in an aging population. This is a current area of research for several demographers and is important for our understanding of aging populations and mortality at the oldest ages in order to make informed policy decisions. The four research questions allow data to be presented to show that the modal age at death for both males and females has increased since 1841, that deaths have compressed into a narrow age range and that there is some evidence of the shifting mortality regime, especially for females in England and Wales in more recent decades. The next section of this report expands on the background and relevance of this project by building on the measurements of mortality and health in England and Wales and how this has changed over time. It also focuses on four of the most recent studies of modal age at death, discussing them and their findings in detail.

2 Background and Relevance

2.1 Introduction

Measuring mortality and life expectancy remains very important for our understanding of longevity, aging societies and mortality improvements of human populations. Life expectancy, the mean age at death according to a hypothetical population subject to a particular mortality experience, has been calculated through life tables as far back as 1841 for England and Wales and remains the leading indicator of population mortality improvements today.

It is important to be able to measure mortality to understand the patterns of death given the demographic situation in England and Wales. Mortality has fallen and rates are improving at the oldest ages. It is also important to be able to compare the health status between countries using L.E. to understand patterns and changes in health and longevity.

This section provides a description of life expectancy as a measure of mortality and its patterns over time in England and Wales. It goes on to discuss the current low mortality in England and Wales and the possible scenarios for understanding mortality trends in years to come. This is expanded on by considering four key pieces of work on the compression of mortality and the modal age at death. This section is designed to give a background to measuring mortality and health and the possibilities for measuring it in the future.

2.2 Life expectancy as a measure of health and mortality

Death registrations were introduced in 1837, which, along with census population data, allowed for the modern analysis of mortality. Life tables were first introduced in a basic format by John Graunt in the 1600s and these tables were concerned with understanding survival (Rowland 2003). Within two decades of Graunt's death, Edmund Halley had developed life tables to the format available today. Since then, life tables have been the demographic tool used to calculate life expectancy.

Life expectancy is a popular and widely understood concept used to document mortality throughout the world and by various professions including demographers, actuaries, policymakers and academics. It provides us with the number of years someone may expect to live at a given age if they were exposed to a given set of mortality rates throughout their life.

Today, L.E. figures are available in various formats including period, cohort, local, national and socio-economic status. Two of the most important variants of life expectancy for understanding health, mortality and aging populations are healthy life expectancy (HLE) and disability-free life expectancy (DFLE). HLE gives us the number of years spent in good health; for England in 2007–09, males could expect to live 63.5 years and women could expect to live 65.5 years in good health. DFLE provides us with the number of years lived without a chronic illness or disability. For England in 2007–09, males have a DFLE of 64.2 years and females have a DFLE of 65.6 years (ONS 2012b).

Median age at death, which is the middle age if all ages at death are in order, can also be easily calculated within life tables and can be used alongside life expectancy within mortality analysis. There are no official median age-at-death statistics in England and Wales. The median age-at-death data calculated from this research is presented in section 4.

2.3 Historical patterns of life expectancy and mortality

The demographic transition that occurred in England and Wales from 1750 onward (Hinde 2003) saw reductions in mortality, followed by declines in fertility after a period of total population growth. With both mortality and fertility rates at low levels, but particularly mortality, life expectancy increased. The improvements in mortality and life expectancy coincided with the stage of the epidemiological transition where populations enter "the age of receding pandemics" (Omran 1971).

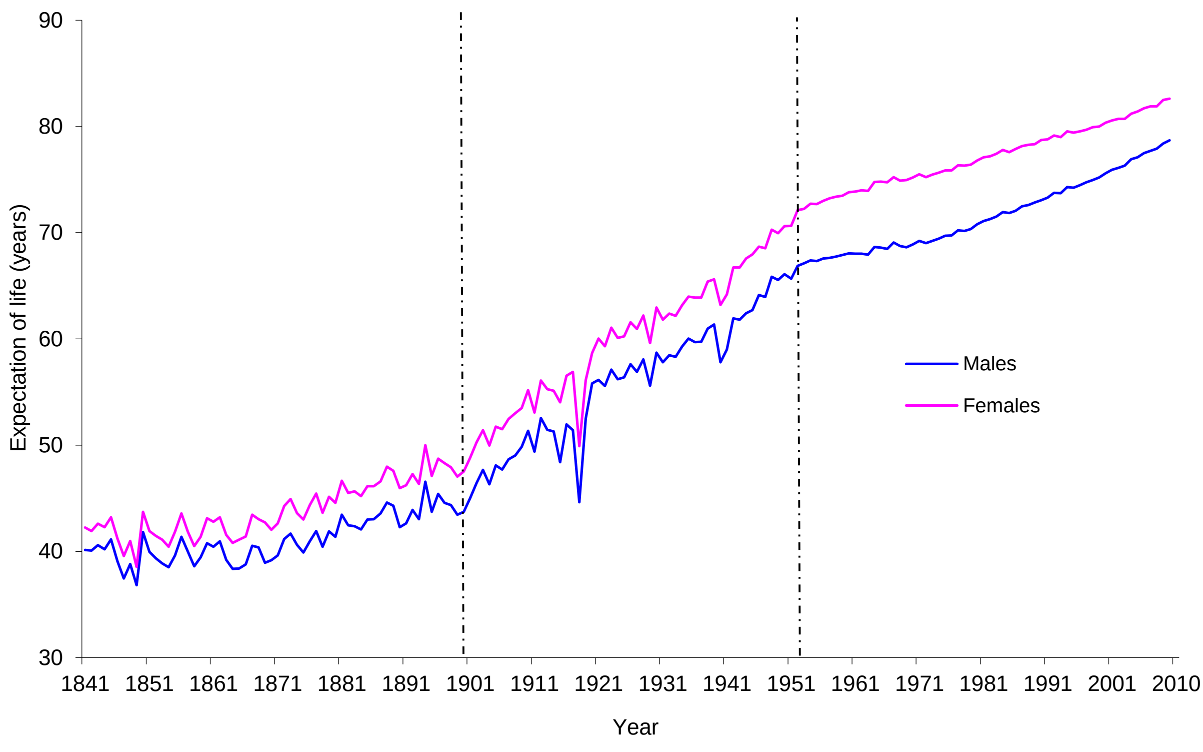
From around 1860 onward, mortality rates began to improve considerably; this was driven by the improvements in mortality at the younger ages. From around 1910 onward, the biggest improvements were made with regard to infant mortality while mortality at the younger and middle ages also continued to improve. As a result, the age-at-death distribution shifted from younger to older ages. It is acknowledged that mortality due to infectious diseases declined over this time, as described by the epidemiological transition theory (Omran 1971), and many reasons are suggested for the declines in mortality due to infectious disease throughout this time. Such reasons include advances in medicine, improvements in sanitation and public health, improvements in nutrition and standards of living, and increased disease resistance in the population.

Improvements in mortality at the younger and middle ages allowed survival to older ages; this was why life expectancy increased, a trend also indicated by a shift to "the age of degenerative and manmade diseases" within the epidemiological transition (Omran 1971). Older people are now more affected by cancers and cardiovascular disease compared to infectious diseases (Hinde 2003, ch. 12).

2.4 Improvements in life expectancy in England and Wales

Figure 2.1 shows life expectancy in years for males and females in England and Wales from 1841 to 2010 (period). The figure illustrates how life expectancy at birth for males and females has changed over time. L.E. has increased from 40.15 years for males in 1841 to 45.03 in 1901, 65.68 in 1951 and 78.70 in 2010. For females, L.E. has increased from 42.24 years in 1841 to 48.83 in 1901, 70.65 in 1951 and 82.60 in 2010.

Figure 2.1 Period life expectancy at birth, 1841–2010, England and Wales



Source: ONS 2011a

The L.E. numbers in figure 2.1 are quite volatile between 1841 and 1901, and we see little improvement over this time. From 1901 to 1951, we see rapid gains in L.E., but we also see the effects of both world wars and the 1918 flu pandemic. From 1951 onward, L.E.

improvements are a lot smoother; we then see steady improvements to date. Female L.E. is consistently higher than that of males. The widest gap was recorded in 1969 at 6.33 years; this has now converged to 3.90 years in 2010. Life expectancy is projected to continue improving for future years (ONS 2011a).

2.5 England and Wales: Recent low mortality

In more recent years, mortality rates in England and Wales have improved at older ages, allowing people to live longer than ever before and increasing the number of centenarians and supercentenarians alive in England and Wales today. Another consequence of maintained low fertility and mortality is an aging population, where the proportions of older people become larger than the proportions of younger people, a trend often characterized by an increase in the median age.

Fries (1980) proposed that there would be a compression of morbidity and mortality in populations experiencing low mortality at younger ages. He noted life expectancy at birth was increasing faster than L.E. at older ages, suggesting an upper boundary to the adult life span, which in turn leads to a rectangularization of the survival curve (Fries 1980, 131). The rectangularization is caused by reductions in premature deaths at younger ages. A larger percentage of people survive at each age, forcing the curve into a rectangular shape, where people survive until they reach the upper limit to the life span. Changes to the age pattern of mortality result. Fries (1980) also predicted that the number of very old would not increase as we reach an upper limit to the life span.

Today, larger percentages of people survive to older ages than ever before, and the existence of an upper limit to life expectancy is much debated as we see continued increases in life expectancy. Life expectancy at birth, as a method used to understand changing mortality, is highly influenced by changing mortality rates at younger ages, especially in low mortality countries. In England and Wales, great numbers of people are living longer than ever before; the mid-2010 estimate for people age 100+ was 11,610 (ONS 2011b). England and Wales having large numbers of older people is due to continually improving mortality rates and survival at older ages. Large numbers of the population surviving to older ages is not only attributable to improvements in mortality at older ages in more recent years but also to previous improvements in mortality rates at younger ages and increases in the sizes of birth cohorts, particularly after World War II.

For countries such as England and Wales, the late modal age at death may be a better measure of life duration than life expectancy and may aid in understanding aging populations and the changes to mortality since the demographic and epidemiological transitions.

2.6 Studying recent trends in mortality

Modal age-at-death studies originate in work on the normal life duration concept by Lexis (1878). More recently, Ouellette and Bourbeau (2011a, 597) wrote: "The late modal age at death is solely influenced by adult mortality and consequently more sensitive to changes occurring among the elderly population." Studying the modal age at death allows us to analyze the changes in mortality above the mode and changes in the age-at-death distribution (survival curve). Although the modal age at death can provide the most common age at death, there is still some variability in the ages at which people die. This can be captured using the standard deviation of ages at death above and around the mode.

As noted above, the mode is influenced by mortality changes at the oldest ages. This makes it a more suitable method for England and Wales, which has an aging population and is experiencing improvements in mortality at these older ages. The mode as a measure of expectation of life is used in comparison to life expectancy, a measure of the mean and median age at death more influenced by mortality at younger ages. These methods seem less appropriate to measure health and mortality in England and Wales.

In the most recent work on modal age at death (Ouellette and Bourbeau 2009 and 2011a; Canudas-Romo 2008; Thatcher et al. 2010), it has become more apparent that Fries' (1980) prediction of an overall compression of mortality, as described in section 2.5, has slowed in recent years even though mortality gains have appeared at older ages. These patterns have "encouraged researchers to distinguish old-age mortality compression from overall mortality compression" (Ouellette and Bourbeau 2011b, 3). It is suggested that the modal age at death and S.D. of life durations around and above the modal age at death can help identify initial compressions of mortality, as suggested by Fries (1980). The more recent end to that compression and a shift of the survival curve or age pattern of mortality to the right can be measured by analyzing the standard deviation above the mode. This is referred to as the shifting mortality scenario and is influenced by continuing improvements in mortality at older ages (Canudas-Romo 2008).

The shifting mortality scenario is only one possible explanation to describe future trends in mortality. Others include complete rectangularization of the survival curve and de-rectangularization of the survival curve. The first would mean that the probability of dying would become extremely small at younger ages right through to the modal age at death, which would have nearly everyone dying at that age. De-rectangularization could occur if we started to see more unequal life spans; lives may become more heterogeneous due to health care or genetics. This would mean certain people would survive much longer than others and so the survival curve would no longer be rectangular. Kachakhidze (2011a) discusses the three scenarios in more detail with regard to the economy and insurance. This report is only concerned with the shifting mortality scenario, which is discussed in more detail in section 5.

2.7 A review of current modal age-at-death studies

To place the project and findings for modal age at death in England and Wales into context, we must first understand the structure and findings from other studies. This section will now take six papers and discuss the methodology and findings made by the authors. Work surrounding modal age at death, compression of deaths and the shifting mortality scenario has all been analyzed recently in papers by Ouellette and Bourbeau, Kannisto, Thatcher et al. and Canudas-Romo among others.

All authors are in agreement that modal age-at-death work originates with Lexis and his concept of normal life durations. All authors are also in agreement that mortality studies in low mortality countries have moved away from the rectangularization of the survival curve, as described by Fries (1980), and that the quest for understanding future mortality patterns is universal. This is because “countries usually go through a compression of mortality regime during the epidemiological transition” (Ouellette and Bourbeau 2009, 1). The rectangularization of the survival curve, related to the compression of deaths, decreases once infant mortality becomes a minor factor, and this is the situation in low mortality countries where mortality is concentrated at older ages.

The mode is used by all authors to investigate future trends in mortality. This is because increases in life expectancy have slowed and are now improving at a similar pace to that of the late modal age at death. “Studying the modal age at death provides an opportunity to have a different perspective of the changes in the distribution of deaths and to explain the change in mortality at older ages” (Canudas-Romo 2008, 1180). This provides relevance for the project on England and Wales as we see life expectancy becoming less meaningful and the need to look at other measures becomes increasingly important for policy, pensions and planning.

Various countries, including Austria, Canada, Norway, the United States, France and Japan, are covered in the papers. The papers all cover more than one country, usually 10–14 countries, and this makes it harder to understand important trends for individual countries as little focus can be given to one country. This is especially true for England and Wales, which has seen little focus within modal age-at-death work. All of the papers cover data for males and females separately; this is important because males and females have experienced very different mortality trends in the past.

In all of the studies, the data is sourced from the Human Mortality Database (HMD). Ouellette and Bourbeau (2009, 5) write that “the high level of data quality offered by the [Canadian Human Mortality Database] and the HMD also makes these databases very attractive.” This is also important for the project on England and Wales as it recommends a credible data source that is available freely. In two of the papers, it is suggested that period data is used; it is unclear in the others. Period data is of most use as it allows the study of changes year on year instead of following a particular cohort of people. It is also only stated in one paper that when extracting the mortality and population data from the HMD, they only extracted from age 10 onward; this is key in focusing on the trends in mortality at the oldest ages, removing the influences of infant mortality. This also provides evidence on which age to start the data for the project on England and Wales. Canudas-Romo (2008) also describes the challenges with using the total population data for France, England and Wales and clarifies that the use of the civilian data for these two countries is used within the findings. This means that the effect of deaths from the world wars is removed from the data. The use of civilian data is discussed in more detail in section 3.

The discussed papers all use different models within their methodology to understand the patterns of modal age at death. Parametric models such as the simple logistic model, Gompertz mortality change model and Siler mortality change model are used by three out of the four groups of authors. The fourth uses a nonparametric model of P-splines, which is the same model applied to the data for England and Wales within this project. The authors suggest this is better than a parametric model because a nonparametric model of P-splines is flexible, has no boundary effects and does not apply rigid theoretical assumptions on the mortality data. In all cases, observed population and deaths data for each country in the form of life tables were extracted from HMD for purposes of comparison to the model findings.

Each of the studies is concerned not only with the changes in the modal age at death, but also the dispersion of deaths at the mode and therefore compression. The authors choose to measure this in several different ways. Table 2.1 summarizes the methods used.

Table 2.1 Summary of methods used in selected studies

Author	Method 1	Method 2	Method 3
Kannisto (2001)	*e*(M)	SD(M+)	$\frac{\mathrm{SD(M+)}}{e(\mathrm{M})}$
Thatcher et al. (2010)	*e*(M)	SD(M+)	-
Canudas-Romo (2008)	SDM	-	-
Ouellette and Bourbeau (2009)	$\widehat{\mathrm{SD}}$(M+)	-	-

Two of the studies look at expectation of life at the mode, *e*(M), and particularly focus on the correlation between that and the standard deviation above the mode, SD(M+). Kannisto (2001) develops this further by looking at the ratio of the two measures. All of the studies then use a measure of S.D. above or around the mode to measure dispersion of deaths. In the majority of cases, this is the root-mean-square of those deviations from the mode (M), which are positive. Canudas-Romo (2008) uses SD(M), which considers all deaths around the mode, unlike the others, which only consider the deaths above the mode. He writes, “The limitation of this measure is that it does not differentiate from child, premature and senescent mortality” (Canudas-Romo 2008, 1193).

All the authors draw clear conclusions that in the low mortality countries studied, compression of mortality above the mode has occurred. This is demonstrated by a decline in the SD(M+) and its associated measures, which is described by Kannisto (2001) as being a resistance to further progress and not a definite limit to longevity. Resistance is caused by death rates at very high ages not falling fast enough to prevent compression (Thatcher et al. 2010, 527). Thatcher et al. also concluded the compression above the mode has been slow and one possible reason could be that death rates at younger old ages are more affected by medical advances and life-saving technologies than death rates at older old ages.

Discussions were also introduced in the literature around heterogeneity of humans, which will maintain some dispersion of lifetimes. Human populations are considered unlikely to have a very low variability at death as Fries (1980) proposed. Differences will continue to be maintained for many reasons, including socio-economic inequalities and health care/plan coverage. These are cited as being factors instrumental in the trends observed in the United States (Ouellette and Bourbeau 2009). Heterogeneity is also an important consideration for the future scenarios of mortality, as discussed in section 2.6.

Canudas-Romo (2008) and Ouellette and Bourbeau (2009) gather some interesting findings for Japan. Canudas-Romo suggests a fall in the number of deaths in Japan at the modal age could indicate a transitional period. Ouellette and Bourbeau build on this by identifying a stop in the compression of deaths above the mode among males and females that indicates an entry into the shifting mortality regime. They also found these trends in other countries among females but not males. The authors conclude that continued observations of the mode may provide clues to the limits of the human life span. Some future scenarios and studies are suggested by the authors. Canudas-Romo (2008) warns that the shifting mortality scenario might also be a transitional stage, as was the compression of mortality, bringing to light the need to be aware of alternative processes within mortality changes.

Consideration is given to the number of caregivers available to look after the elderly, the effect that may have on the mortality of the very old and the need for research into the relationship between longevity and health. This too could impact future scenarios of mortality, especially in low mortality countries.

Earlier work by the authors focused on understanding the compression of mortality above the mode. More recently, and specifically in work by Ouellette and Bourbeau, there has been a tendency to focus on the shifting mortality scenario in low mortality countries. These studies have not focused on England and Wales and so have not discussed the shifting mortality scenario evidence in great detail there. This project and report aims to build on previous work by taking the method for smoothing mortality rates used by Ouellette and Bourbeau and applying it to data for England and Wales. This research contributes to the existing literature by focusing on the findings for England and Wales in greater detail.

2.8 Summary

This section provided background and relevance to this project by explaining the current common measure of mortality, life expectancy and its patterns, and explaining why this may no longer be relevant for England and Wales by introducing a possible alternative, modal age at death. The section introduced and discussed life expectancy as a measure of health and mortality by explaining the development of early life tables, and by exploring the various formats it is produced in, including HLE and DFLE. The historical patterns of life expectancy in England and Wales were described, followed by the demographic and epidemiological transition that led to low mortality in England and Wales today. Trends and improvements in life expectancy data were then presented and discussed. L.E. for males in England and Wales stands at 78.70 years and 82.60 years for females. The section then described the low mortality demographic situation in England and Wales, which fed into how recent trends in mortality have been studied and the possibilities for future trends. This is where the concept of measuring the modal age at death was brought in as an alternative to L.E. because of the changes in the age-at-death distribution; this has moved studies away from the compression of mortality and toward three possible scenarios for the future. Following this, several key studies were discussed in more detail. The findings showed that mortality compression above the mode has occurred in the countries studied, and that in Japan there is evidence of the shifting mortality scenario. These trends were also found for females in other countries studied. The next section of this report looks at the data and methodology used within this project.

3 Data and Methodology

3.1 Introduction

This section of the report describes the methods and data used to obtain the results and findings in the following section.

The mode or modal age at death is the most common age at death. Characteristically, the age-at-death distribution is bimodal for a human population. This means we commonly see a peak of deaths at age 0, more specifically soon after birth, and a second adult or late modal age at death. This is because mortality is high soon after birth, particularly within the first four weeks. Mortality then falls and remains low throughout the teenage and younger adult years. Mortality increases throughout the rest of adult life. This project specifically focuses on the second or late modal age at death.

The mode is used to monitor death distributions at older ages; this is because the mode is solely influenced by changes to deaths at the oldest ages. This method is particularly suitable for a country with low mortality at the younger ages and with a dominance of adult mortality reductions in more recent years. The curve of deaths for England and Wales is not symmetrical and life expectancy at birth becomes a less useful indicator of mortality in countries where changes in mortality are occurring at older ages (Institute and Faculty of Actuaries 2011, 9). England and Wales has a suitable age pattern of mortality for analyzing the modal age at death.

The variability of deaths around and above the mode can be measured using the standard deviation around and above the mode. The S.D. is used to measure the level of compression or dispersion of deaths and also allows us to distinguish overall mortality patterns and compression from old age mortality patterns and compression. It has become important to understand and distinguish the two mortality patterns suggested above due to the historic improvements in mortality at younger ages that led to strong compression of deaths; this has now slowed but important improvements in mortality have been seen at older ages recently (Ouellette and Bourbeau 2011a, 2).

3.2 Data

England and Wales was chosen to study as they comprise the primary area of interest for work at ONS. Data can be obtained back to 1841, providing us with one of the longest time series available. Recent studies within the same topic area have not solely focused on England and Wales; this piece of research will fill a gap in the literature. Jan. 1 population estimates and deaths data by single year of age (up to age 109) for 1841 to 2010 for England and Wales were extracted from the Human Mortality Database (HMD). Data for the civilian population (population estimates exclude the military and death counts exclude deaths to the military abroad) and the total population (includes civilian and military population, and includes military deaths abroad) were extracted for males and females separately. The datasets differ only for the interwar periods of 1912–20 and 1939–50 because of the increased number of deaths, especially to males, during both world wars. The deaths data is based on age at last birthday and the deaths are assumed to have occurred evenly throughout the year they refer to.

Age-specific death rates (ASDR) (simply deaths at a specific age divided by the population at that age for a given year) were required for use later in this project. To accurately produce these mortality rates on an age-period basis, midyear population estimates were required. To do this, the Jan. 1 estimates were converted to midyear population estimates through a simple interpolation method. This involved adding the estimate for age x in year x and the estimate for age x in year x + 1 and dividing by 2 to give a midyear population estimate.

Once the midyear estimates were calculated, the resulting datasets of population counts and death counts were standardized or cut off at age 103 for females and age 100 for males. This is needed to remove any zeros from the data, which affect the smoothing method and smoothing package chosen to use with the data.

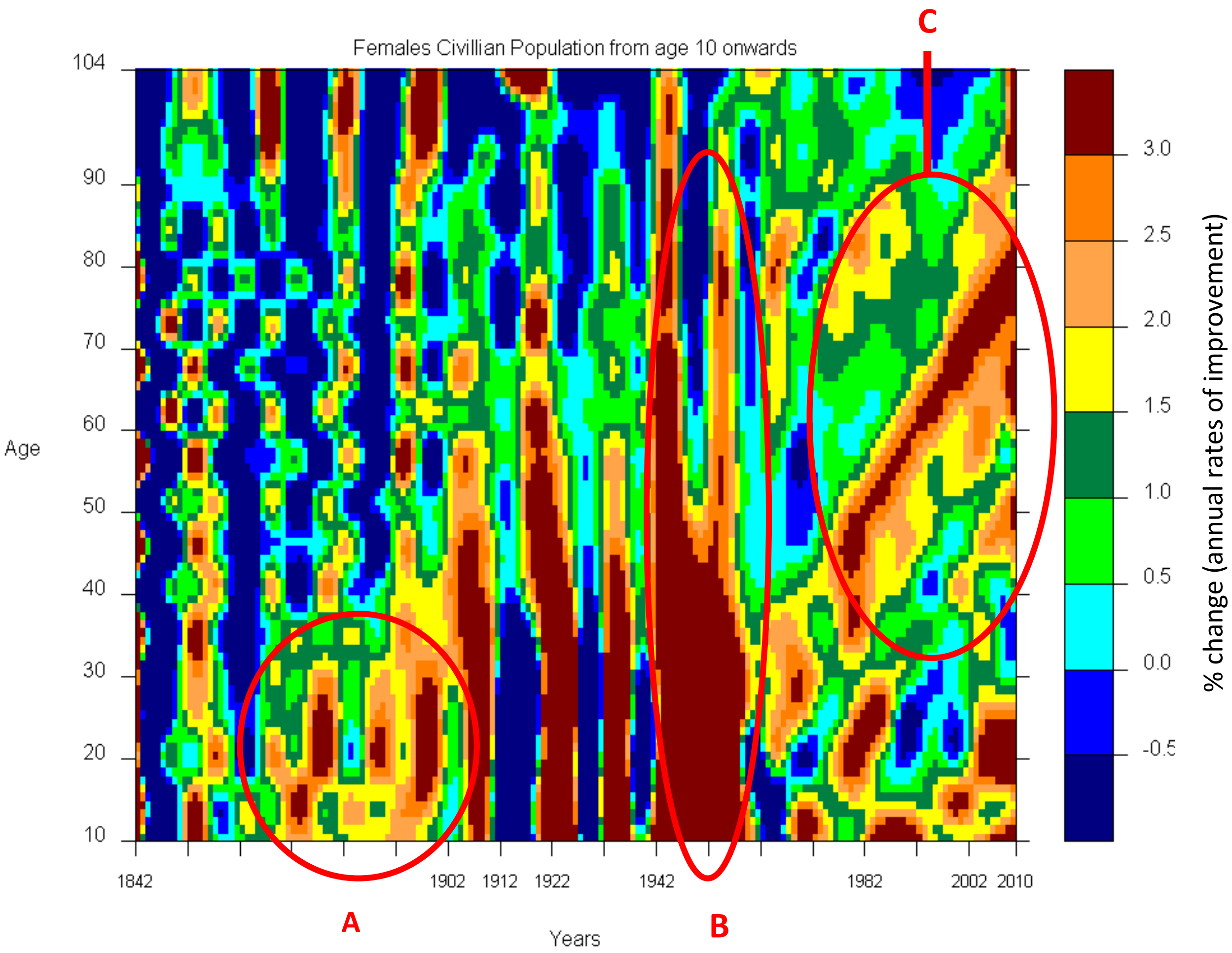
Eight datasets (16 files) were taken forward; these have been listed in appendix I. This included one set for males for the civilian population and the total population and the same for females. For each of those sets, one set of data started at age 0 and another at age 10 because of the need to understand the impact of smoothing the death rates while including infant and child mortality and the impact of not including them. The decision on which data to use is discussed in section 3.2.

Smoothed ASDR (M_x) were obtained using the nonparametric smoothing method of applying two-dimensional P-splines to the data. This is done using the package MortalitySmooth within the statistical program R (R Development Core Team 2012). P-splines are a combination of B-splines (basis splines) and penalized likelihood, which is where a penalty term is applied to the log-likelihood of the data. The B-splines provide flexibility for accuracy and the penalty ensures that the fit of the spline is smooth. The deaths are assumed to be Poisson counts but the method can accommodate over dispersion. For more information, see Currie, Durban and Eilers (2004) and Camarda (2012). The syntax used to smooth the data within MortalitySmooth can be found in appendix II.

This smoothing approach removes year-on-year fluctuations of deaths caused by period effects such as war and flu. The method was used in work by Ouellette and Bourbeau (2011a). A benefit of this method is that it smoothes in two dimensions (rates throughout age and over time are smoothed together). This means mortality trends can be analyzed over both ages and time and trends are more refined and true to the actual underlying mortality trends. A nonparametric approach is considered to be flexible and does not place any theoretical mortality assumptions onto the data. “Because mortality developments generally display regular patterns, using smoothing approaches is a more natural choice for analyzing mortality changes than imposing a model structure,” wrote Camarda (2012, 2).

Once the smoothed ASDR were created, the datasets needed to be extrapolated to age 125 for males and females. This is necessary to be able to use the data within a life table. The extrapolation applied to the data is a linear regression model and is in-line with the method used in the English life tables and national population projections. Once a full set of ASDR were available, some quality assurance (Q.A.) could take place. This was conducted by calculating the annual percentage change in ASDR. The values could then be imported into a Lexis diagram in the form of a heat map. An example is shown in figure 3.1.

Figure 3.1 Rates of mortality improvement, females, England and Wales, 1841–2010



Source: Author's analysis of HMD data

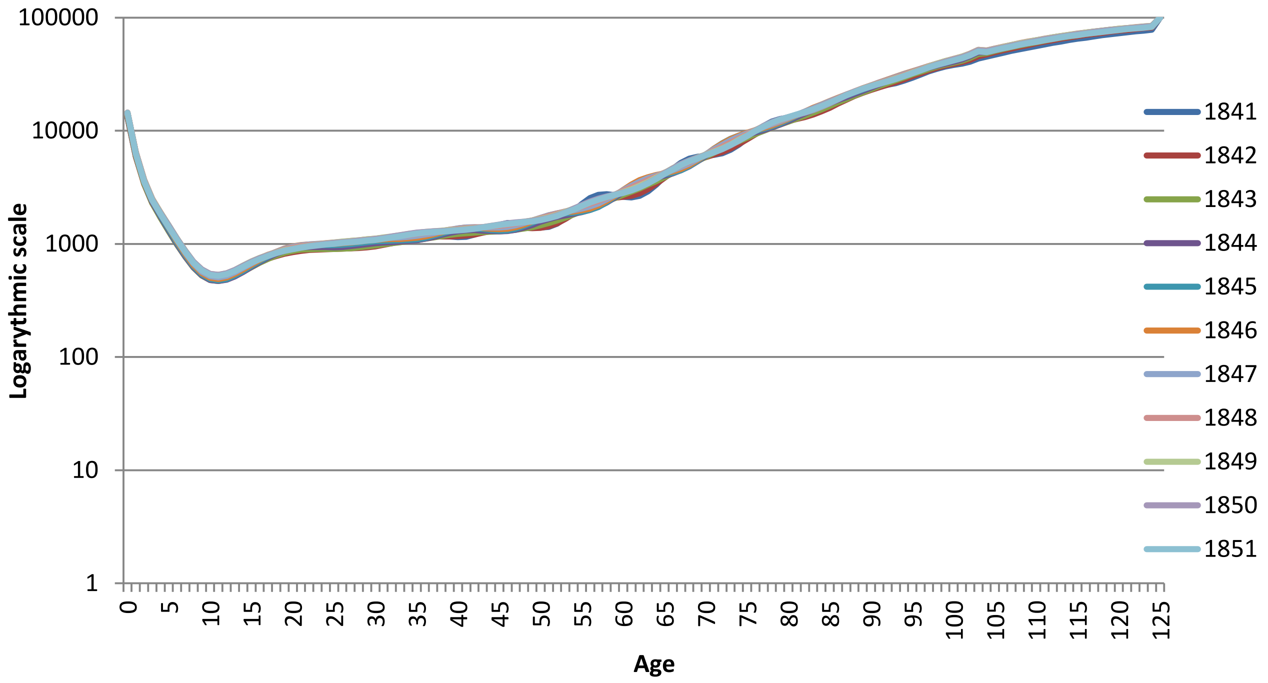
The heat map allows us to identify improvements in mortality shown by the brown areas and worsening mortality as shown by the blue areas. The maps make it easy to identify trends over time, and also to ensure that the newly smoothed data is demonstrating the historic trends we would expect to see for England and Wales. Figure 3.1 shows (A) the improving mortality of younger people in the late 1800s, (B) improving mortality at all ages after World War II and (C) the continuing cohort improvements for the generation born between 1924 and 1938. For more information about this cohort, see Goldring et al. (2011).

The ASDR, referred to from now on as M_x, were converted into the probability of dying between exact ages, which are denoted by the notation q_x. Formula 3.1 shows the formula used to create the probability of dying between exact ages from the M_x values. This is calculated for each single year of age for every year 1841–2010.

Formula 3.1 $$q_x = \frac{2\,M_x}{2+M_x}$$

Once the q_x values were produced, further Q.A. could be carried out. This involved graphing the q_x values on the logarithmic scale. This enabled us to see the characteristic tick shape in the data. An example is shown in figure 3.2.

Figure 3.2 Female q_x per 100,000, 1841–51, England and Wales



Source: Author's analysis of HMD data

The q_x shows us that the probability of dying after birth is high; this then continually falls until around age 10, after which the probability of dying steadily increases over the life course. By plotting the q_x values, we can ensure the data display the trends we would expect to see. It also allows us to select points in the data that need further investigation.

The q_x values were used as the starting point in the construction of life tables for each calendar year. The life table enables us to create life expectancies, by measuring the effect of mortality levels at each age on a hypothetical population—usually consisting of 100,000 males and females at birth. This is known as the radix. The table also allows the monitoring of survival at each age. By using the life table, the probability of survival or levels of mortality are applied to a set population, which removes the effects of changing population size and allows us to solely see the effects of changing mortality. This means the number of deaths at each age are standardized.

The q_x values were used in four life table templates employed by ONS. These are simply Excel spreadsheets that use macros to calculate the columns of a life table with standard life table methodology. (For more details, see Rowland 2003 or Hinde 1998). The calculations are possible by hand, but the templates provide ease and convenience. The final columns available for use include:

q_x: The probability of dying between exact ages (displayed per 100,000)

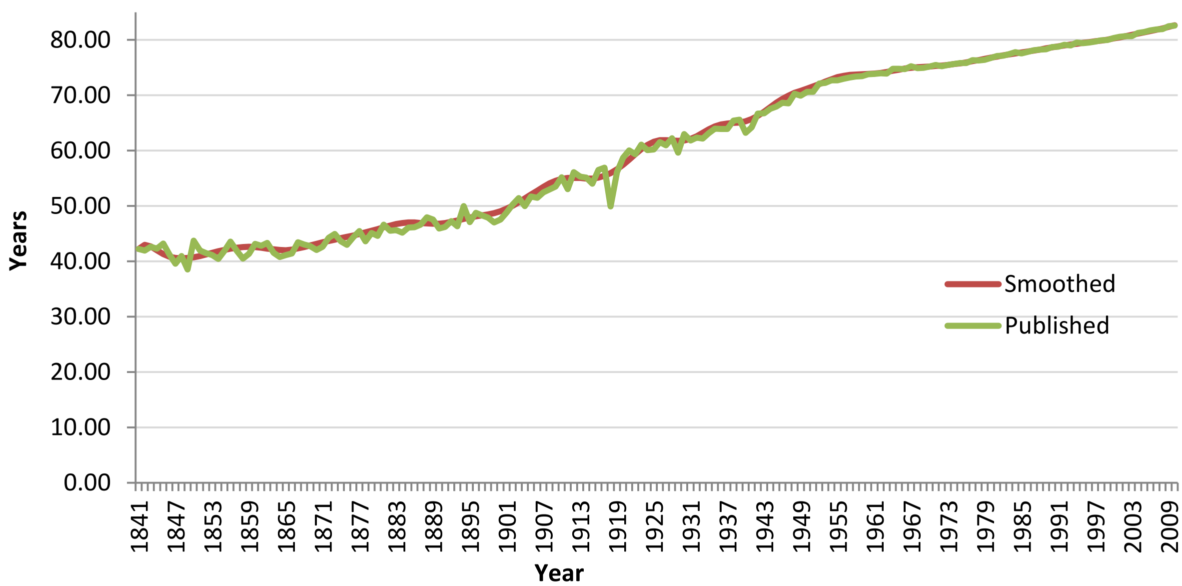
l_x: The number alive at exact age x; this is 100,000 at age 0

d_x: The number of deaths between exact age x and exact age x + 1

e_x: The expectation of life at exact age x

At this stage, some further Q.A. was conducted. This involved using the life tables to extract e_x at birth for each year from 1841–2010. This could then be compared to the national published life expectancy at birth figures for England and Wales over the time period. Again, this was used as an opportunity to identify any points in the data that deviated from the expected trend. This is demonstrated in figure 3.3.

Figure 3.3 Female life expectancy at birth, England and Wales, 1841–2010



Source: Author’s analysis of HMD data and ONS 2010-based period life expectancy

Figure 3.3 shows how the smoothed data produces the same trend in expectation of life at birth to the national figures for females in England and Wales. The effects of the smoothing on the data can be clearly seen as it removes the annual, sometimes sharp, fluctuations in life expectancy but maintains the overall trends.

Once the life tables were created, the decision of which data to work with needed to be made. The d_x figures were extracted for males and females, for the total population data and for the dataset smoothed from age 10 and from age 0. The data was extracted for all ages until the last age in the dataset, 125. The data is on a period basis and is therefore extracted for each year; this allows us to see changes over time rather than following a particular cohort. The d_x figures could then be sorted to reveal the age at which the most deaths occur: the modal age at death. It quickly became apparent that the total population data would not be suitable for use. This is because the data is affected by the elevated number of deaths during the two war periods and the flu epidemic in 1918 (Dunnell 2008). This is especially true for males, where a third modal age at death is created in the data. Because this interrupts the underlying trends in modal age at death, it was decided the data was not appropriate.

The civilian data was extracted in the same way and then ordered to reveal the modal age at death. This data set was less affected by the two war periods and flu deaths. The civilian population data therefore was selected for use. It was decided the data smoothed from age 10 would be used in the research, because

- Modal age at death is age 0 for earliest years in the time series
- "Human mortality generally increases quite smoothly after about age 10, but it shows a steep decline between birth and this age due to infant and child mortality" (Camarda 2012, 21)
- The data smoothed from age 10 allows the removal of the effects of child mortality
- Other similar studies have also smoothed from age 10 or 14

Civilian population data smoothed from age 10 for males and females were used in the calculation of modal age at death and this is the data referred to from now on. The d_x figures for each year were extracted for males and females separately. These figures were then ordered to reveal the modal age at death; this was further refined using formula 3.2. This provides the modal age at death to four decimal places by fitting a quadratic polynomial to the death distribution data.

Formula 3.2 $$\mathrm{M}(t) = x + \frac{[d(x,t)-d(x-1,t)]}{[d(x,t)-d(x-1,t)]+[d(x,t)-d(x+1,t)]}$$

Note: M(t) is modal age at death at time t; x is the age with the highest number of deaths from the life table at time t (Canudas-Romo 2010).

The modal age-at-death data was then ready for further analysis, which is discussed in the data and results sections.

The next stage of work was to calculate the standard deviation around the mode and the S.D. above the mode for males and females every 10 years from 1841. The method chosen uses standard methodology for calculating a S.D.

3.3 Standard deviation around the mode

For a given year, the d_x figures (deaths) were extracted from the life table and kept in age order (10–125); for each age, the mode to four decimal places was subtracted from the age at death. The difference between the mode and the age at death for each age was then squared. The squared value was multiplied or weighted by the d_x figure, the number of deaths that occurred at that age. The weighted values were summed for that year and divided by the total number of deaths, 100,000 in this case. The square root of that figure becomes the S.D. The S.D. in this case is the number of years the deaths for the population are spread around (above and below) the modal age at death. This allows us to measure the dispersion of deaths. The weighting of the squared difference is used because we have grouped, and not individual, observations.

There were some considerations and assumptions made when calculating the S.D. around the mode. It is assumed that deaths at age x last birthday are spread evenly between ages x and x + 1. Hence deaths occur, on average, at age x plus a half (*Age x* + 0.5). We also needed to take into account that we have age at death x + 0.5, but we have the modal age at death to four decimal places, or exactly. Adjustments have been made within the S.D. calculations for deaths that occur at the age category where the modal age at death falls within (*x*). The method apportions the numbers dying above and below the exact modal age at death within the age-at-death category that the mode falls within (*x*). This is done to ensure we do not over- or underestimate those dying above and below the mode. The Excel syntax used can be found in appendix III. Formula 3.3 summarizes the S.D. method used.

Formula 3.3

$$\mathrm{SD} = \sqrt{\left[\frac{\sum\langle\{(Age\ x+0.5)-\mathrm{M}\}^2\rangle d_x}{n}\right]}$$

Note: Where *Age* is the integer age at death; n is used because we are dealing with a population and not a sample.

3.4 Standard deviation above the mode

This is calculated in a similar way, but we only use the d_x figures from the mode until the last age at death for a given year. The S.D. above the mode is calculated using formula 3.3. When we look at deaths above the mode, the total number of deaths change. This is because we are no longer dealing with the whole life table population of 100,000 people. The mode varies and so does the number of deaths occurring at and above the mode.

The same assumptions apply as for the S.D. around the mode, and we also make an adjustment for the age category in which the modal age at death falls within (*x*). This time, we apportion the deaths as before but we are only interested in those deaths that we apportion to occurring after or above the mode. In this case, the S.D. tells us the number of years that the deaths for the population are spread above the mode.

The findings of S.D. around and above the mode are discussed in the results and discussion sections.

3.5 Additional indicators

Alongside the methods described in this section, some other indicators are used to analyze the data. The indicators include period life expectancy at age 10 from the life table, median age at death from age 10 calculated from the life table and expectation of life at the mode, *e*(M). The median age at death is also looked at in combination with the lower quartile (L.Q.), which is the age at which the 25,000th death falls, and the upper quartile (U.Q.), which is the age at which the 75,000th death falls for total deaths of 100,000. The interquartile range (IQR), the difference between the L.Q. and the U.Q., are also presented along with a measure of the gap between the U.Q. and the last age at death for each year. The ranges are used as a comparison to S.D. above and around the mode.

These additional indicators help to substantiate my findings and strengthen the arguments made within the findings discussed later in this report.

3.6 Ethical considerations

When undertaking analysis, it is important to consider risks and ethics. This work relies solely on the collection and analysis of secondary data from a standard and freely available source. Risk is therefore low. The use of secondary data means human participants are not involved; this removes any ethical considerations with regard to children, people with disabilities or the elderly.

The data is extracted and analyzed at the national level; this removes any risks of disclosure of personal information. The source of the data is a well-recognized, established international database, meaning that the data is robust and of good quality.

Reflexive considerations and an evaluation of the appropriateness and effectiveness of the methodology are discussed in section 6. This project was undertaken according to the University of Southampton risks and ethics procedures.

3.7 Summary

This section has described the datasets used in the analysis, their source and the format they are in. It went on to describe the processes that the datasets went through, including interpolation, smoothing methodology, extrapolation and Q.A. The section continued to explain how life tables were constructed, which allows the extraction of d_x figures to identify the modal age at death. The concepts of S.D. around and above the mode, as a measure of the compression of mortality, were introduced and described. Additional indicators were described and the risks and ethics were considered. The next section displays the results and findings of the modal age-at-death work.

4 Results and Description A

4.1 Introduction

This section and the next present and describe the results from the research undertaken on the data for England and Wales. Section 4 covers the first proposed research question: How has the modal age at death in England and Wales changed over time?

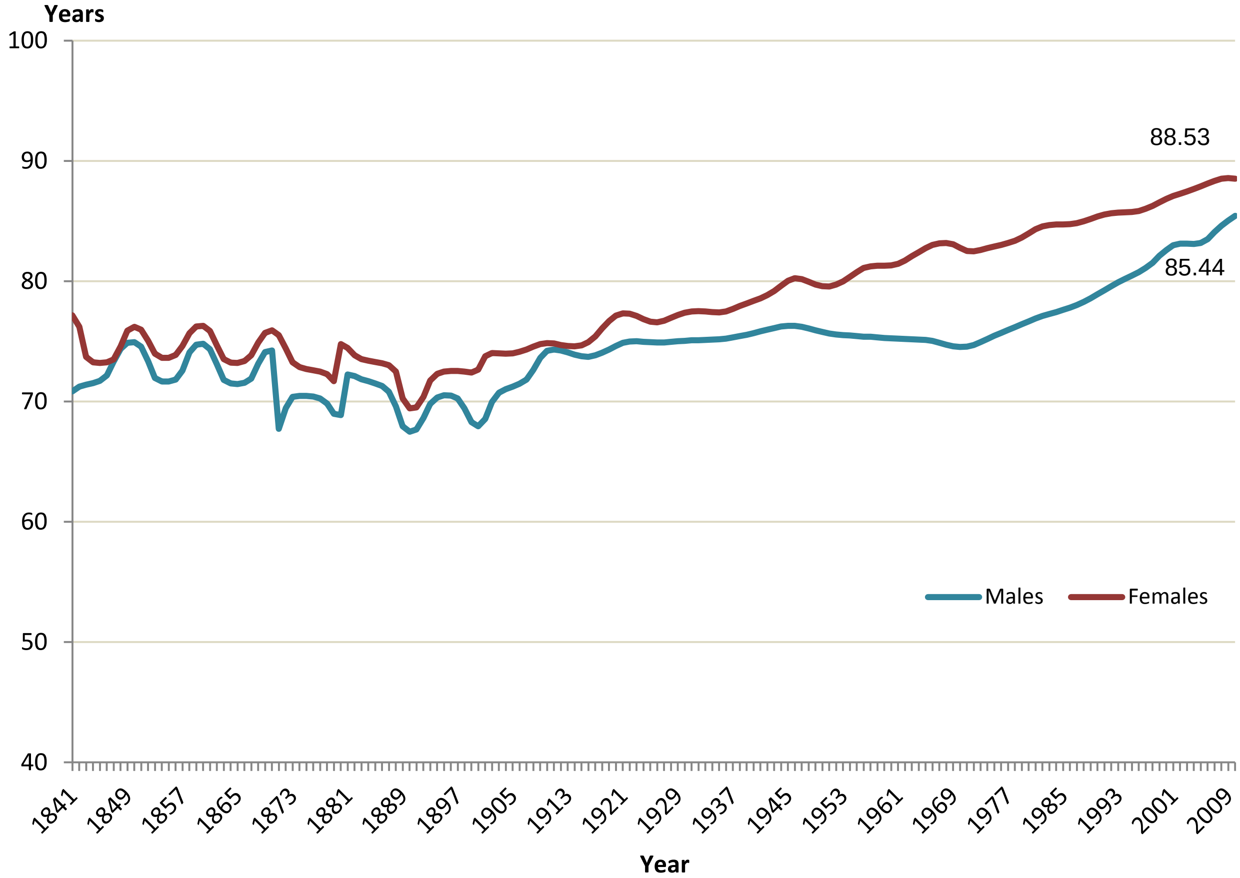
As discussed in section 3.1, modal age at death refers to the late modal age at death. All results displayed in this section and beyond refer to civilian population data smoothed from age 10 onward for England and Wales.

4.2 How has the modal age at death changed over time?

Figure 4.1 shows that modal age at death has increased for males and females in England and Wales. For males, modal age at death in 1841 was 70.85 years; it rose to 85.44 years in 2010. For females, it was 77.16 years in 1841 and 88.53 years in 2010. Modal age at death fluctuated until around 1911; this is thought to be due to low numbers of people reaching older ages and therefore the low number of deaths at older ages. The consistency of the peaks and troughs, which can be seen in figure 4.1, may also be due to the lack of rebasing of population estimates following historic censuses.

Growth in modal age at death has accelerated from 1900 onward, but particularly from 1970 onward; this is particularly so for males, who have seen a steeper incline in the data line after 1970, as shown in figure 4.1. Female modal age at death is consistently higher than male modal age at death. The male and female lines are close until 1900; they then diverge until their widest gap of 8.47 years in 1969. Male and female mode then converges to the difference seen in 2010 of 3.09 years. Females have seen a more steady and gradual improvement compared to males. This is due to the improvements in the mortality rates at older ages seen at an earlier stage for females compared to males, who do not see large improvements until the 1970s, which is when we begin to see their mode increasing. This is because the mode is a measure affected by mortality at the oldest ages.

Figure 4.1 Late modal age at death, England and Wales, 1841–2010



Source: Author's analysis of HMD data

Table 4.1 provides modal age at death every 20 years for males and females.

Table 4.1 Late modal age at death, England and Wales, selected years

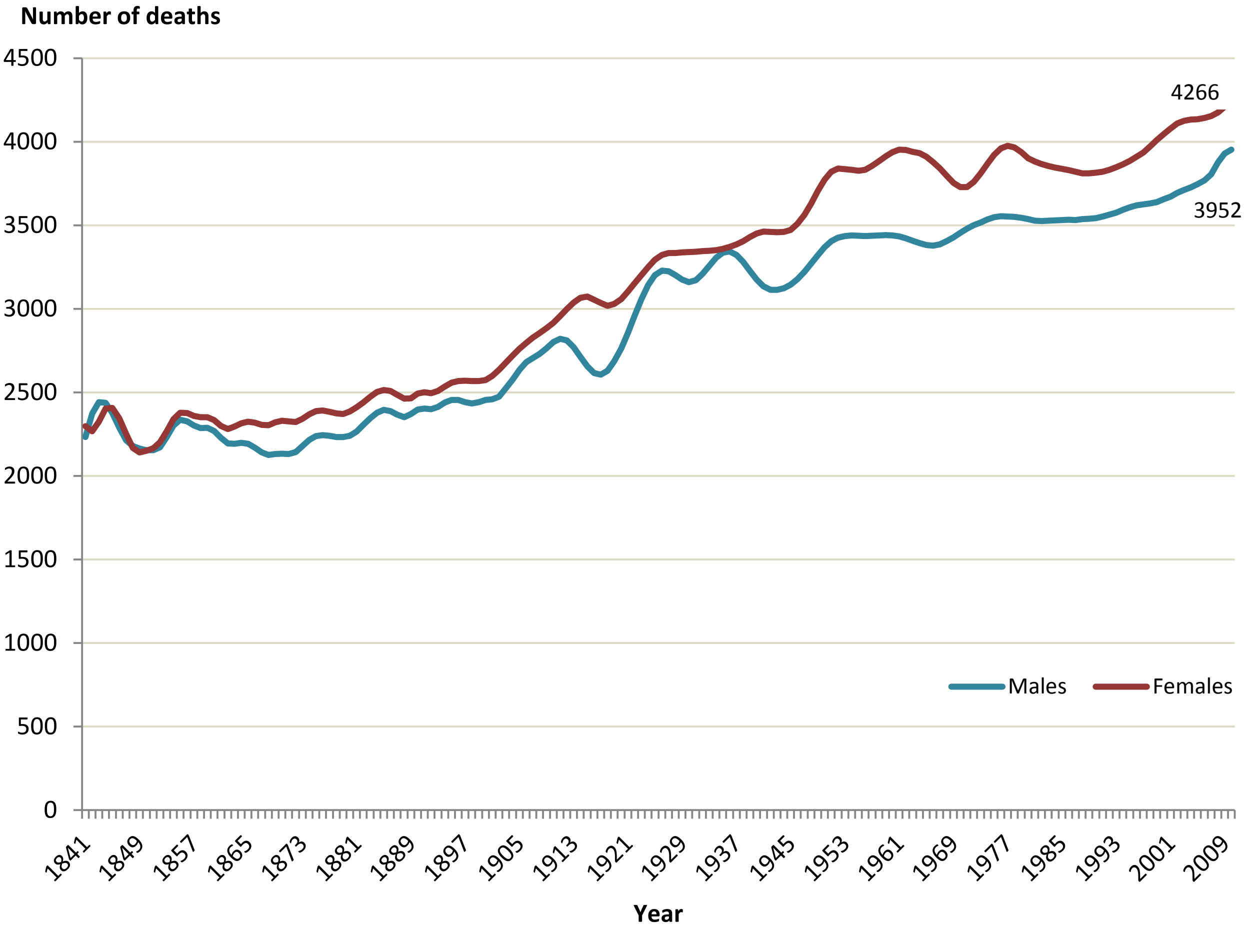
	1841	**1861**	**1881**	**1901**	**1921**	**1941**	**1961**	**1981**	**2001**	**2010**
Males	70.85	74.35	72.26	68.55	74.88	75.84	75.22	76.90	83.00	85.44
Females	77.16	75.86	74.47	73.77	77.32	78.58	81.46	84.31	87.09	88.53

Source: Author's analysis of HMD data

4.3 Deaths at the mode

Deaths at the modal age are becoming more common, as shown in figure 4.2. In 1841, 2,232 male deaths occurred at the mode in England and Wales, which is 2.2 percent of all deaths from the original 100,000 deaths in the life table. For females, the equivalent figure was 2,298 deaths, 2.3 percent of deaths. The number of deaths occurring at the mode has increased over time and, in 2010, 3,952 male deaths occurred at the mode (4.0 percent) and 4,266 female deaths occurred at the mode (4.3 percent) in England and Wales.

Figure 4.2 Number of deaths* at the modal age at death, England and Wales, 1841–2010



Source: Author's analysis of HMD data
*Number of deaths shown are the numbers taken from the life table, not actual deaths. The numbers are based on a standardized population of 100,000 people at age 10. These are the number of deaths at age last birthday, not exact modal age at death. These represent the age at last birthday that the most number of deaths occurred at from the life table. Deaths are from age 10 onward.

Until 1850, the numbers of male and female deaths at the modal age were quite similar. They then diverged until one of their widest points around 1918–21. This is a period at which mortality and therefore life expectancy, as shown later in figure 4.7, was affected by the flu epidemic. The deaths attributable to the war for military deaths abroad have been removed by using data for the civilian population, but the flu deaths and war deaths occurring in England and Wales remain. For females, there is little effect on the modal age at death, but it does decrease slightly from 1911–16; the numbers dying at that age reduce for the years 1915–19. This is because deaths are then spread out across the age-at-death distribution as the flu affects many age groups. For males, we see the modal age at death fall slightly between

1911 and 1916, but deaths occurring at the mode fall more sharply for males from 1911–17 compared to females. This is because many age groups had excess deaths from the flu, but males were more affected then females (Dunnell 2008, 16).

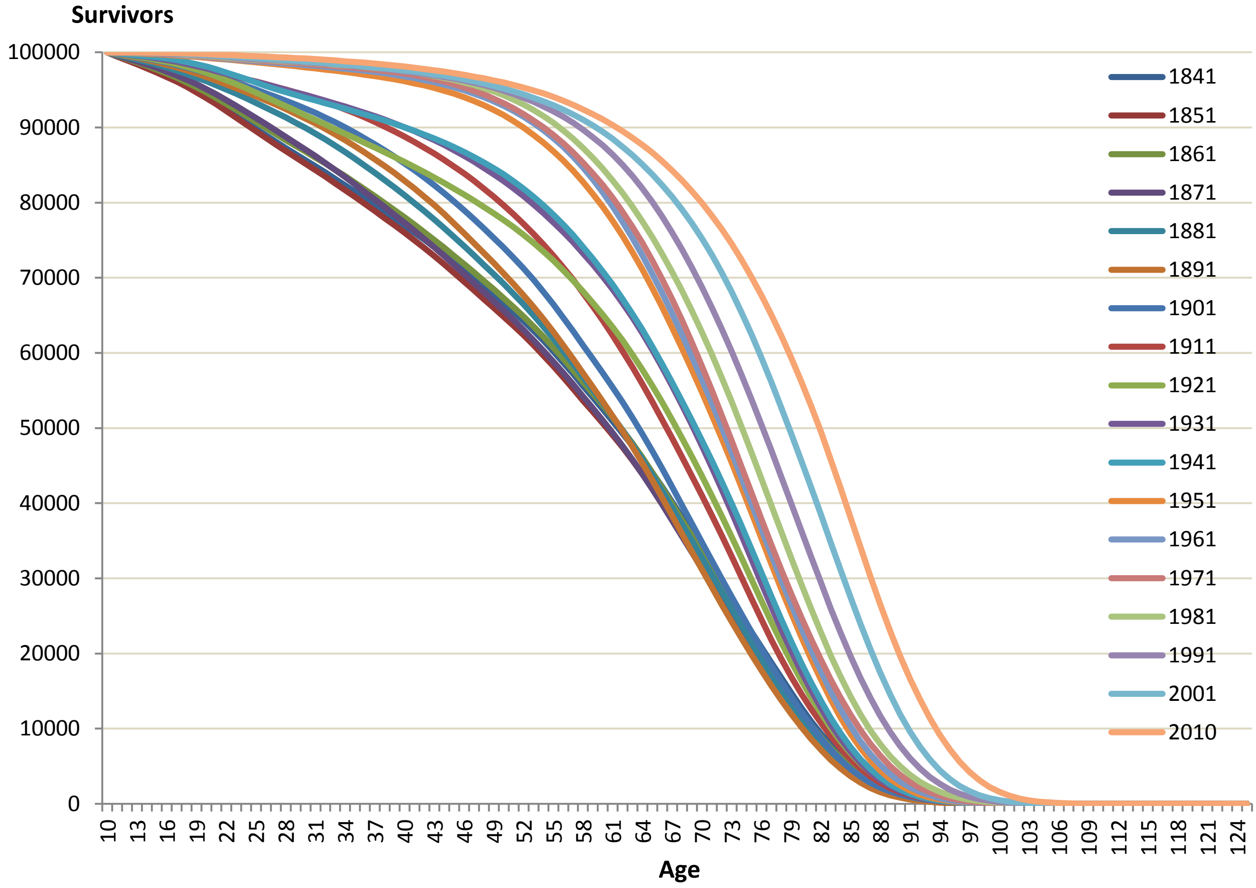
From 1937–43, we see a fall in deaths at the mode for males. This can be attributed to World War II and the deaths occurring in England and Wales during the war. Figure 4.2 also shows that this affected males rather than females. The increases in deaths at other ages were not large enough to affect the mode because the data used in the analysis was for the civilian population, as discussed in section 3.

Moving further along in time, we see a fall in the number of deaths at the mode around 1961–62 until 1970–71 and this time it is more pronounced for females compared to males in England and Wales. Further research suggests there were high numbers of excess winter deaths around this time (Sweet 2011, 24). Females tend to live longer than males and there are larger numbers of females at older ages, so we see excess deaths at the oldest ages affecting females more than males. Looking at the actual number of female deaths at this time (Dunnell 2008), we can see the elevated number of deaths for ages 65 and over. The increase in deaths is not enough to affect the mode but it does spread deaths out across the age-at-death distribution. The change in deaths at the mode for females can also be seen in figure 4.6.

To understand more about how the modal age at death has increased over time, figures 4.3 and 4.4 can be useful. These graphs show survival curves for males and females separately and they are showing the numbers of survivors (l_x) at each exact age from the original 100,000 life table population at age 10; every 10 years are shown on the graph. Figure 4.3 shows how survival at all ages has improved over time although there has been relatively little improvement at the very oldest ages. For each year the line is moving out as the number of people surviving at each age increases. The biggest improvements are seen at the middle to late ages (35–70), and as the line pushes out, the rectangularization of the survival curve occurs (Fries 1980). Initially reductions in disease and infant mortality provide improvements at younger ages; more recently, improvements have been made around circulatory diseases and cancer, improving survival at the middle and older ages as discussed in section 2. The largest gains can be seen between 1941 and 1951 at the middle ages. In England and Wales in

2010, 70,000 males from the original 100,000 males survived to age 77; in 1841, only 18,800 males survived to age 77. In England and Wales in 2010, 80,000 females from the original 100,000 females survived to age 77; in 1841 only 21,200 females survived to age 77. As the downward slope becomes steeper, it is associated with a reduction in the variability of age at death, which is shown in figures 4.5 and 4.6, and it is also shown in the modal age at death becoming more common in figure 4.2.

Figure 4.3 Male survival curve, England and Wales, 1841–2010, selected years

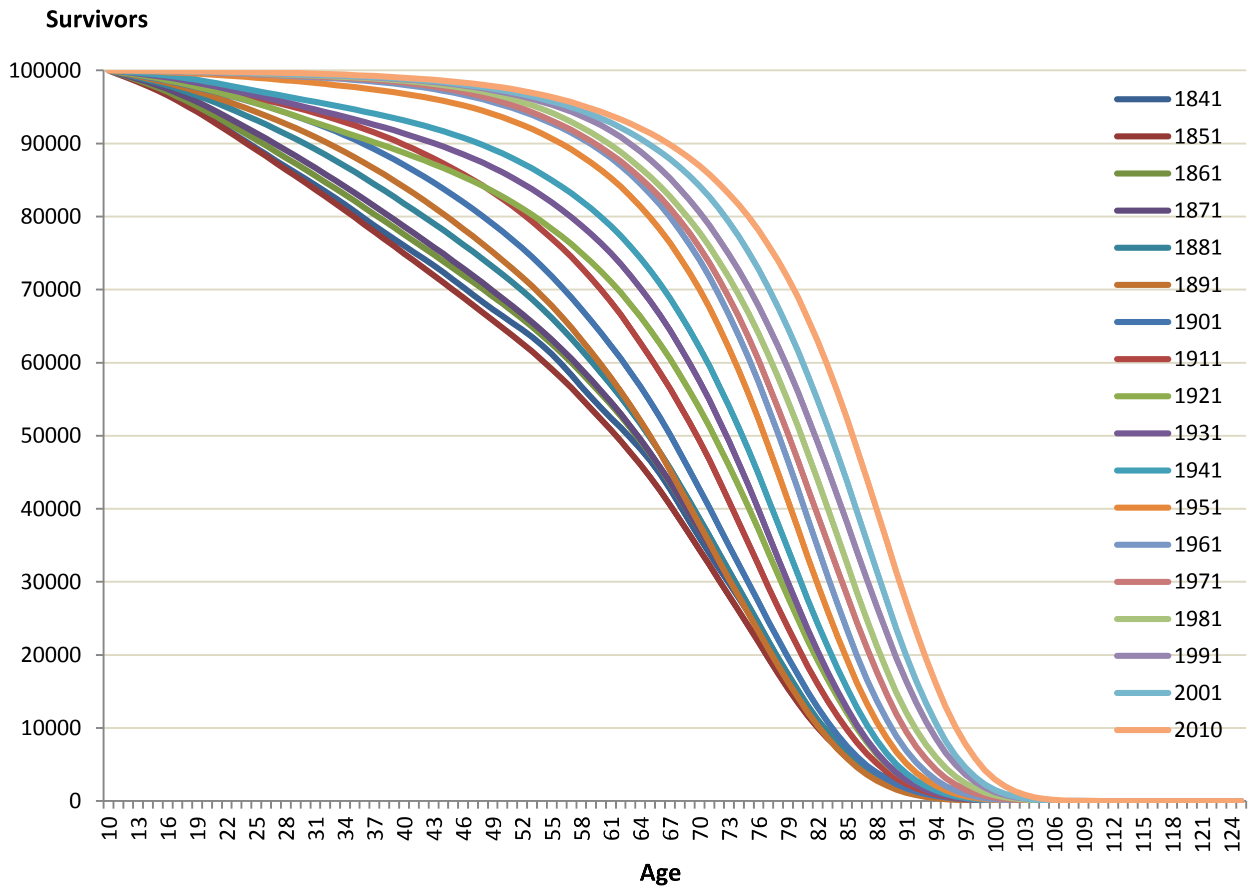


Source: Author's analysis of HMD data

Figure 4.4 shows the survival curves for females have a very similar pattern to the males'. Females tend to have higher levels of survival compared to males and so greater strength in the rectangularization of the survival curve. The largest improvements are seen between the years 1941 and 1951; this can also be seen in area B in figure 3.1. The large improvements can be seen because of elevated mortality during the war that improves once the war is over. Improvements could also be associated with the continued rationing impact on diets, the founding of the National Health Service in 1948 and the continued effects of immunization.

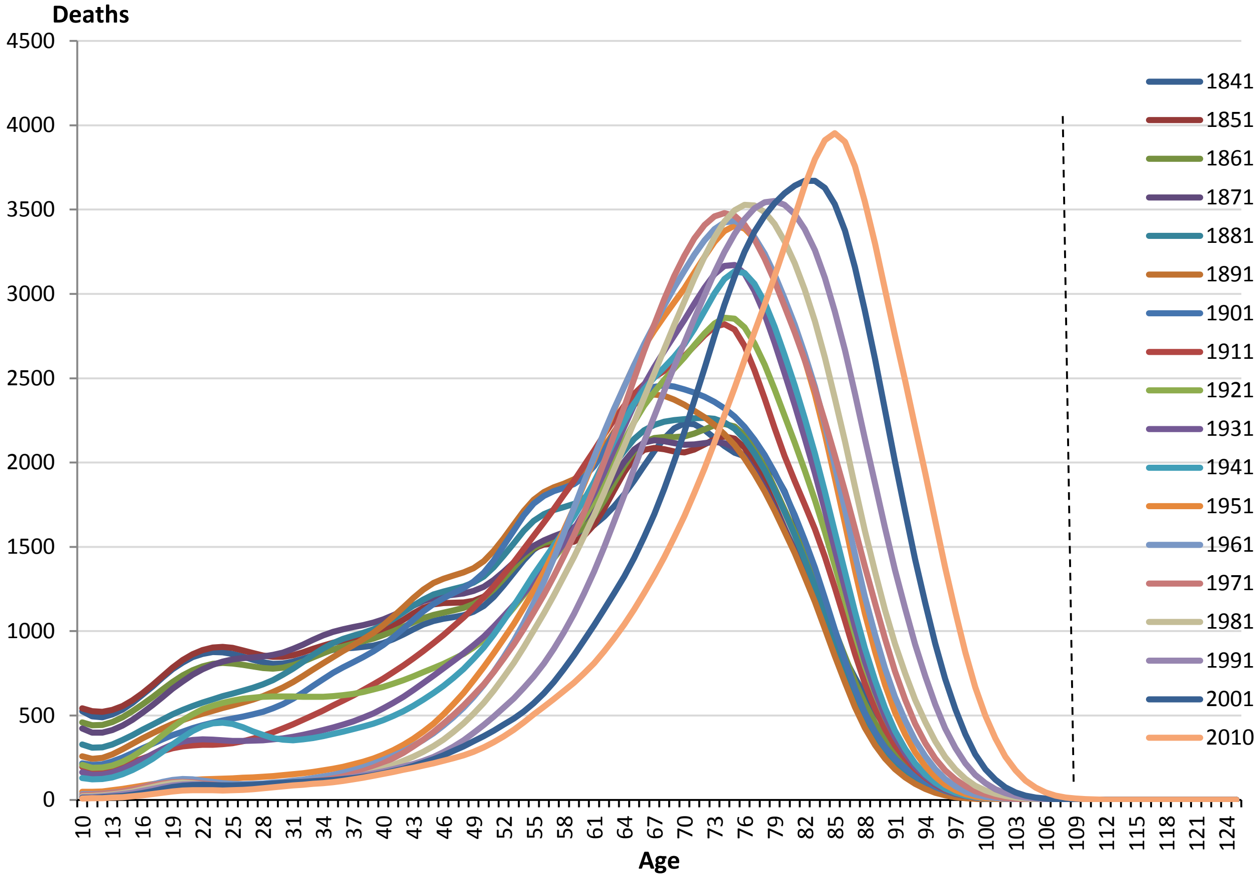
For both males and females, the survival curves for 1911 and 1921 cross over at the younger and middle ages; this is due to the effects of the 1918 flu, which was also seen in figure 4.2. For males, we see little improvements between 1931 and 1941 and this is because of mortality during World War II. It is more pronounced for males and is also demonstrated in figure 4.2.

Figure 4.4 Female survival curve, England and Wales, 1841–2010, selected years



Source: Author's analysis of HMD data

Figure 4.5 Male deaths, England and Wales, 1841–2010, selected years



Source: Author's analysis of HMD data

From the life table, we can also extract the age-at-death distribution (d_x) to see how this has changed over time. Figure 4.5 shows how the peak of deaths (mode) moves to the right over time, which also demonstrates how modal age at death has increased over time. The peak also increases in height; this is the increasing number of deaths occurring at the mode. It is also seen that the shape of the curve has compressed over time. The curve has narrowed as deaths compact into a shorter age interval. The variation in age at death has reduced with age at death becoming more standardized. Figure 4.5 demonstrates the compression of mortality as proposed by Fries (1980), although the data for England and Wales has not reached the levels of compression or commonality of the mode Fries proposed. This leads us to look for new scenarios for recent and future mortality in England and Wales and is discussed in the following research questions.

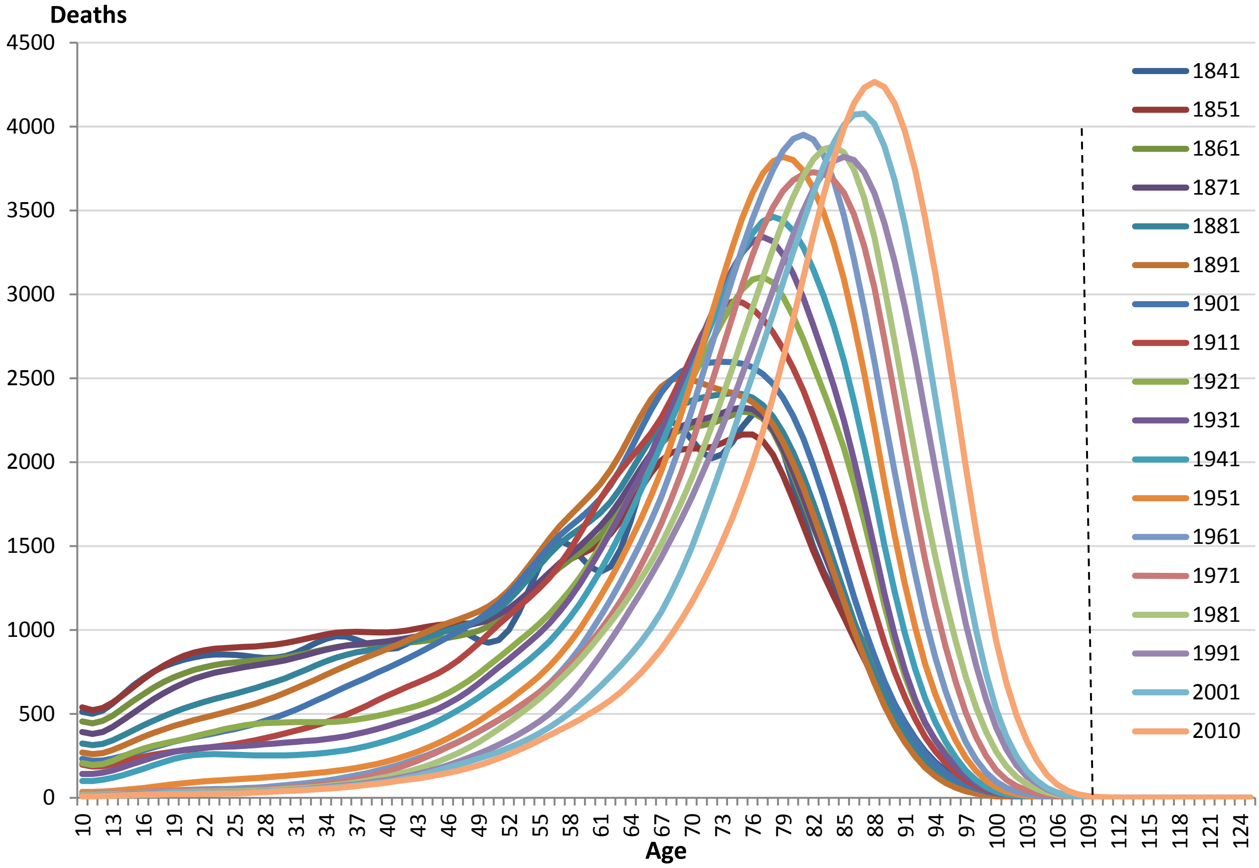
It is seen that deaths at the youngest ages have been reduced while deaths at older ages have increased as survival and mortality rates improve, as demonstrated in previous figures. The dashed line in figures 4.5 and 4.6 is used to show how the right-hand slope has become steeper; this is because the mode has improved faster than the improvements in mortality being made at the oldest ages. This is also demonstrated by a decrease in the S.D. above the mode or the compression of mortality above the mode, which is discussed in section 5.3.

There is a large increase in deaths at the mode between 2001 and 2010. This is most likely to be due to the golden cohort[2] reaching the modal age at death. As so many have survived to the oldest ages, they increase the deaths at and after the modal age at death.

Figure 4.6 displays the age-at-death distribution for females in England and Wales. Females show the same patterns as males although the female mode is higher and deaths at the mode are also higher. For females, there is an interesting change in the curves between 1961 and 1971; instead of the curve continuing to move to the right and increase in height as in previous years, we see the curve reduce in height and widen compared to the data for the years either side. This is also demonstrated by an increase in the SD(M). This observation was also noted in figure 4.2, where female deaths at the mode fell between the 1960s and 1970s. The data for this 10-year period in more detail (table 5.1) shows that the modal age at death increases to a peak of 83.19 years in 1968; the SD(M) also increases to a peak in 1967 after which it decreases. An increase in SD(M) suggests a reduction in compression of mortality; at the same time, SD(M+) continues to decrease until around 1966-67, which suggests deaths occurring above the mode are compressing into a shorter age interval above the mode.

[2] The golden cohort has experienced improved survival rates compared to the generations born before and after them. They are born between 1924 and 1938, but particularly those born between 1931 and 1932.

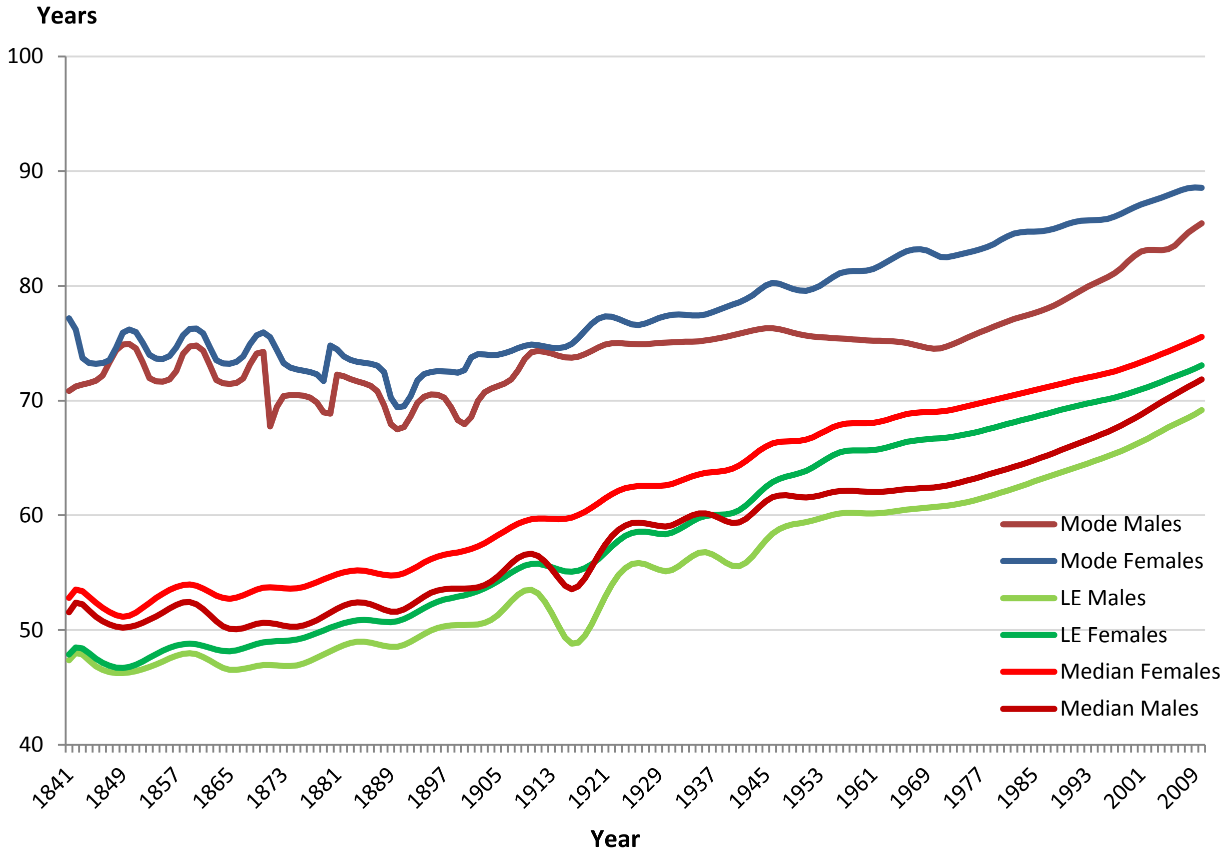
Figure 4.6 Female deaths, England and Wales, 1841–2010, selected years



Source: Author's analysis of HMD data

To understand how modal age at death has changed over time, it can be useful to compare to other measures of life duration. Figure 4.7 shows how the mode has changed along with period life expectancy at age 10 and median age at death from age 10, which have all been extracted from the same life table. The mode starts higher than the median and L.E. (mean); this is because the median and the mean are more affected by deaths at the youngest ages. This also indicates the age-at-death distribution is negatively skewed. All three measures see convergence and divergence between males and females at the same time. Median age at death and L.E. cross over, but both increase toward the mode over time; this is because mortality shifts to older ages and therefore people live longer, which pushes up the values of the mean and the median. The mode remains the highest value.

Figure 4.7 Alternative measures of longevity, England and Wales, 1841–2010, from age 10*



Source: Author's analysis of HMD data
*Life expectancy is period life expectancy at age 10; median age at death is also from age 10.

4.4 Summary

Modal age at death has increased for males and females since 1841. Increases in the modal age at death accelerated from 1900 onward and particularly from 1970 for males. Modal age at death for males and females has converged and the number of deaths occurring at the mode for males and females has increased since 1841. Females have a higher modal age at death and a higher number of deaths occur at the mode for females compared to males.

The survival curves and age-at-death distributions show the drivers of how modal age at death has increased. Survival at all ages has improved over time and rectangularization of the survival curve has occurred as the modal age at death has become more common. The age-at-death distributions show how deaths have compressed into smaller age ranges, pushing up the height and therefore the number of deaths occurring at the mode. The curves of deaths move to the right as the mode increases; the right-hand side of the curve becomes steeper as the modal age at death increases faster than mortality improvements at the oldest ages for both males and females in England and Wales.

The mode is consistently higher than L.E. (mean) and the median, although both the mean and the median have converged with the mode as mortality at older ages has improved and the population has aged. The next section discusses the results relating to the second research question.

This section has displayed and described the results used to answer the first research question. The next section will provide results and a description used to answer two of the remaining research questions.

5 Results and Description B

5.1 Introduction

This section covers these research questions:

a) How has the S.D. of ages at death around and above the mode changed over time?
b) Is England and Wales demonstrating a shifting mortality scenario?

5.2 How have SD(M) and SD(M+) changed over time?

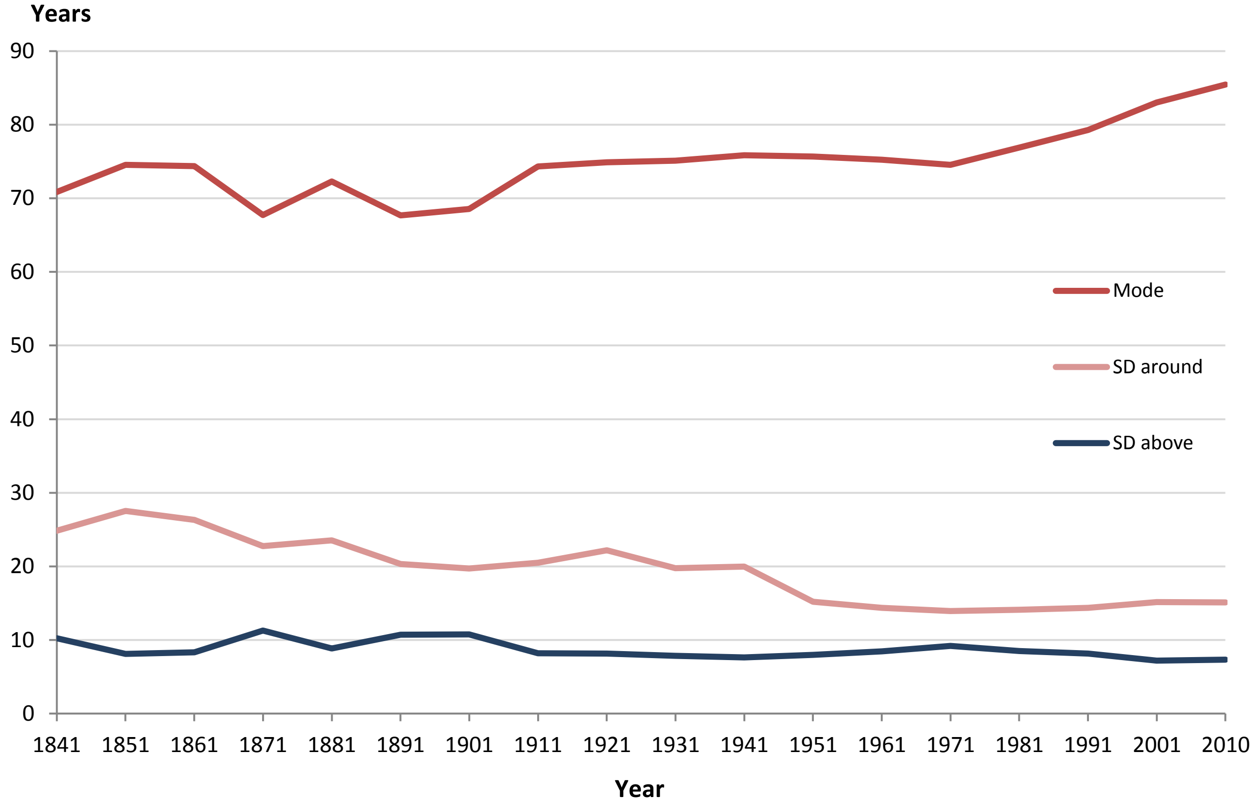
Standard deviation is used as a measure of variation and dispersion. The measure summarizes the changes in the shape of the age-at-death distribution curve, and therefore the spread of deaths from the mode. The S.D. is used to identify compression of mortality. Within this section, it is important to separate overall mortality compression as measured by S.D. around the mode from mortality compression at the oldest ages as measured by S.D. above the mode to understand the compression of mortality and the move toward an alternative hypothesis, as described in section 2 and explored in the next question.

5.3 Overall mortality compression

Figures 5.1 and 5.2 show that for males, the SD(M) has decreased from 24.85 years to 15.10 years in 2010. This shows overall mortality has compressed over time, which is also seen in figure 4.5, where the age-at-death distribution curve has narrowed. A compression of mortality means variation in life span has also lessened, or "the ages at which people die have become less variable" (Institute and Faculty of Actuaries 2012, 6). Since about 1950, overall compression of mortality has been stagnating between 14 and 15 years, indicating a slowing or completion of large compressions of overall mortality for males.

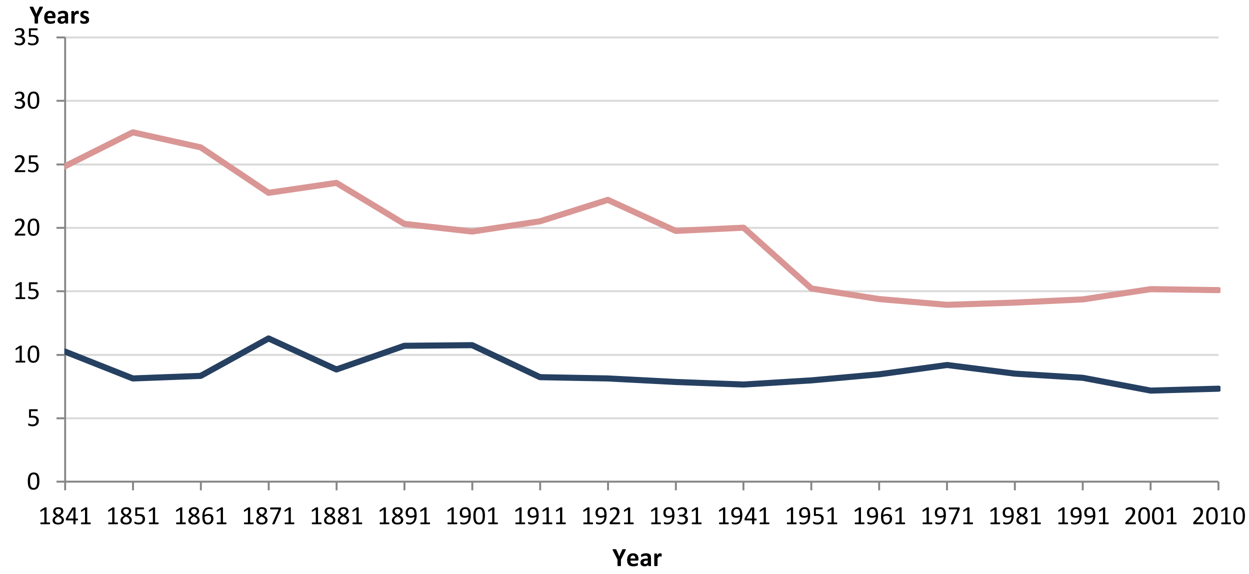
Figure 5.1 also shows that as the modal age at death increases, variation of the life span decreases, demonstrating negative correlation as the two lines diverge. This is associated with low mortality countries where the mode is able to increase as the population ages and low mortality below the mode means life spans become more standardized, "so compression of mortality is consistent with a reduction in variation" (Institute and Faculty of Actuaries 2012, 6).

Figure 5.1 Male modal age at death, SD(M) and SD(M+), England and Wales, 1841–2010



Source: Author's analysis of HMD data

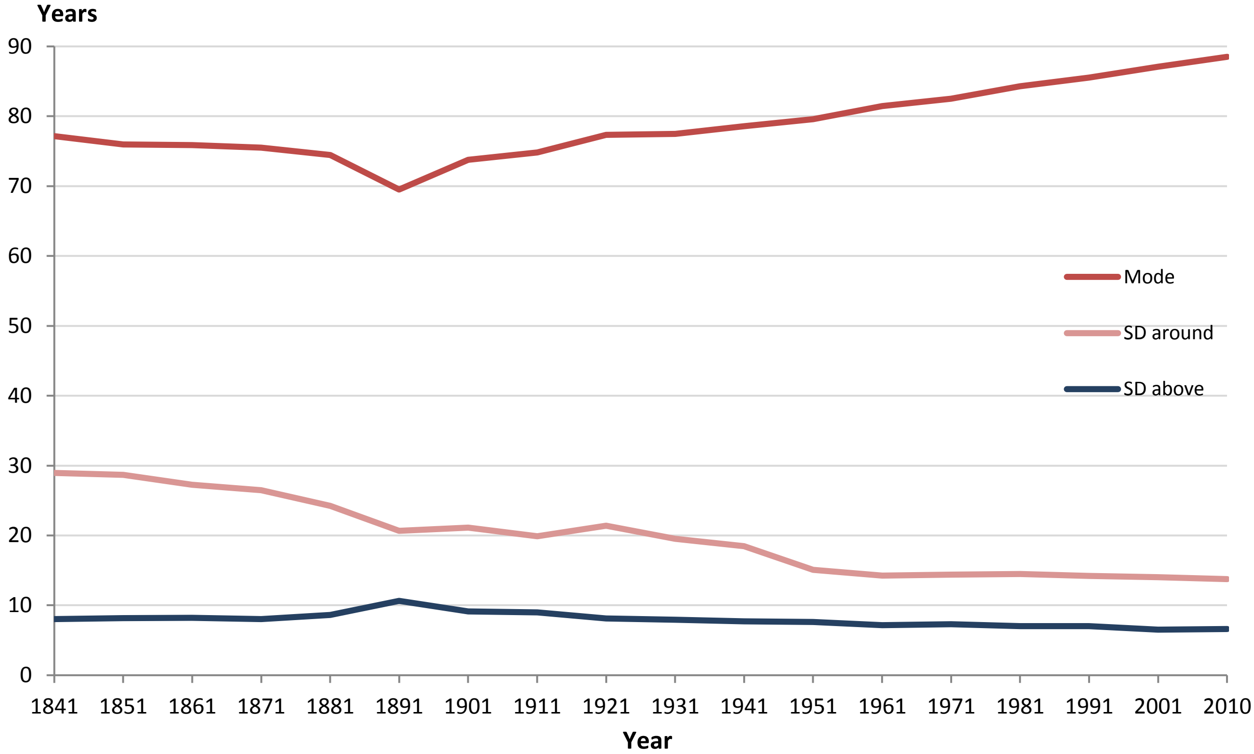
Figure 5.2 Male SD(M) and SD(M+), England and Wales, 1841–2010



Source: Author's analysis of HMD data (Legend is as graph above)

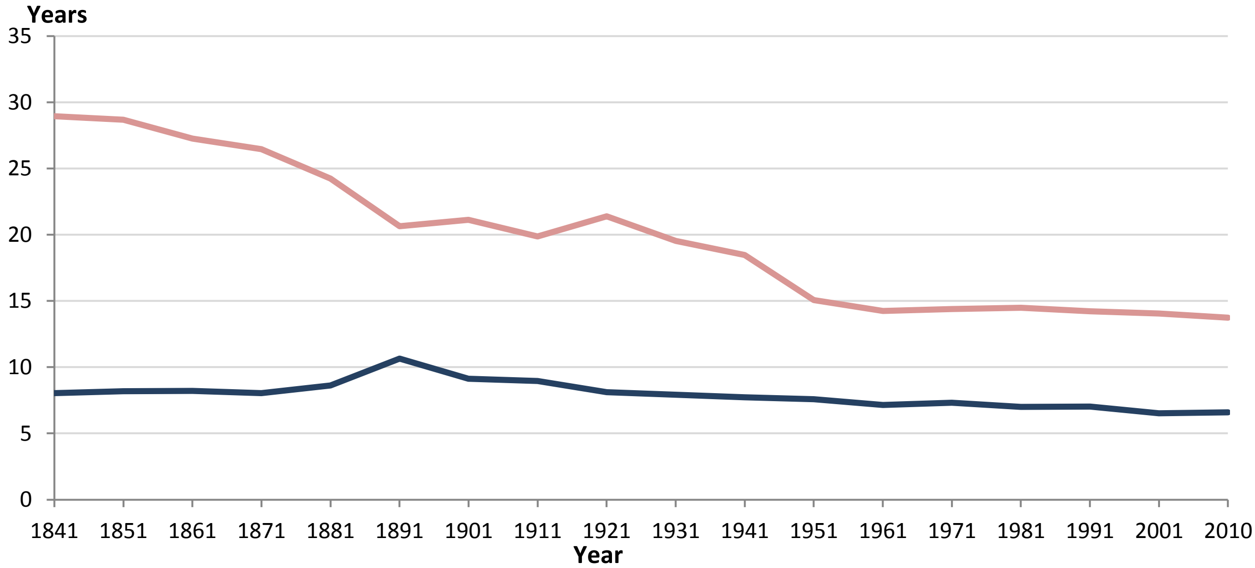
Figure 5.3 shows a similar pattern for females S.D. as for males. Females have seen a larger decrease in SD(M), from 28.96 years in 1841 to 13.74 years in 2010, even though females started with a higher SD(M). The decrease in SD(M) means that overall mortality has compressed for females, and SD(M) has been stagnating for females since 1960 at around 14 years, although females have seen some decreases (compression) in more recent years.

Figure 5.3 Female modal age at death, SD(M) and SD(M+), England and Wales, 1841–2010



Source: Author's analysis of HMD data

Figure 5.4 Female SD(M) and SD(M+), England and Wales, 1841–2010



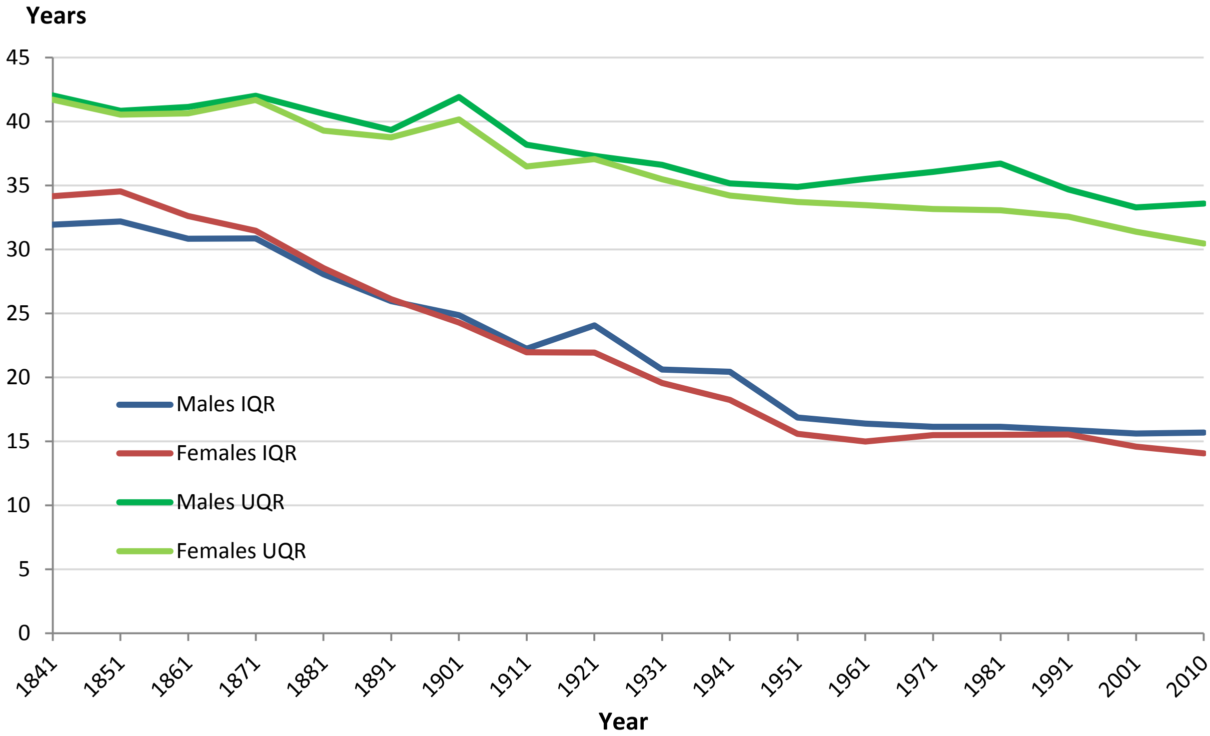
Source: Author's analysis of HMD data (Legend is as graph above)

5.4 Mortality compression above the mode

The SD(M+) has decreased over time from 10.24 years in 1841 to 7.32 years in 2010 for males. This shows that mortality above the mode has also compressed. Thatcher et al. (2010) highlighted Kannisto's finding, when investigating the dispersion of deaths above the mode, that the right-hand slope of the age-at-death distribution was being flattened so the distribution became compressed. This can be seen in figure 4.5, where the right-hand side of the curve moves toward the dashed line. The reductions in SD(M+) have declined at a slower pace compared to the reductions in SD(M). Figure 5.2 shows little stagnation in SD(M+) as fluctuations continue for males, suggesting changes in the age-at-death distribution above the mode are continuing. The negative correlation seen previously between the mode and SD(M) does not seem to hold between the mode and SD(M+); this suggests that variation in the age at death for older people (ages above the mode) has not reduced greatly (Institute and Faculty of Actuaries 2012, 7).

SD(M+) has decreased from 8.05 years in 1841 to 6.60 years in 2010 for females; this is a smaller decrease compared to males, but SD(M+) remains lower for females compared to males. For females, the age-at-death distribution has changed at a faster pace than for males and modal age at death is higher for females; this may explain why we have seen less compression above the mode for females. Even though mortality above the mode has compressed for females, this has been quite stagnant since 1960 at around seven years. Again the data for females (figure 5.3) shows negative correlation between the modal age at death and SD(M) as it did for males; the correlation is less so for SD(M+), demonstrating there has been little reduction in the variation in life spans above the mode.

Figure 5.5 Interquartile range and upper-quartile range, England and Wales, 1841–2010



Source: Author's analysis of HMD data

To further understand how the SD(M) and SD(M+) have changed over time in England and Wales, the interquartile range (IQR) and upper-quartile range (UQR) in figure 5.5 can also be used. The IQR is the difference between the age at which the 25,000th death occurs and the 75,000th death occurs from the original 100,000 population of the life table. The UQR is the difference between the age at which the 75,000th death occurs and the last age at which death occurs in the life table for each year. The IQR is used in comparison to the SD(M) and shows a very similar trend of mortality compression from the median age at death to the upper and lower quartiles as the range between the points decreases in size. The UQR is used in comparison with the SD(M+) and again it shows a very similar trend for both males and females, with the smaller compression of deaths above the mode. This measure has demonstrated less stagnation compared to the SD(M+); this may be because the upper quartile changes, but the last age at death from the life table is relatively constant. This is not the case for SD(M+), where the numbers dying at and before the last age at death in the life table change more substantially.

5.5 Are England and Wales demonstrating a shifting mortality scenario?

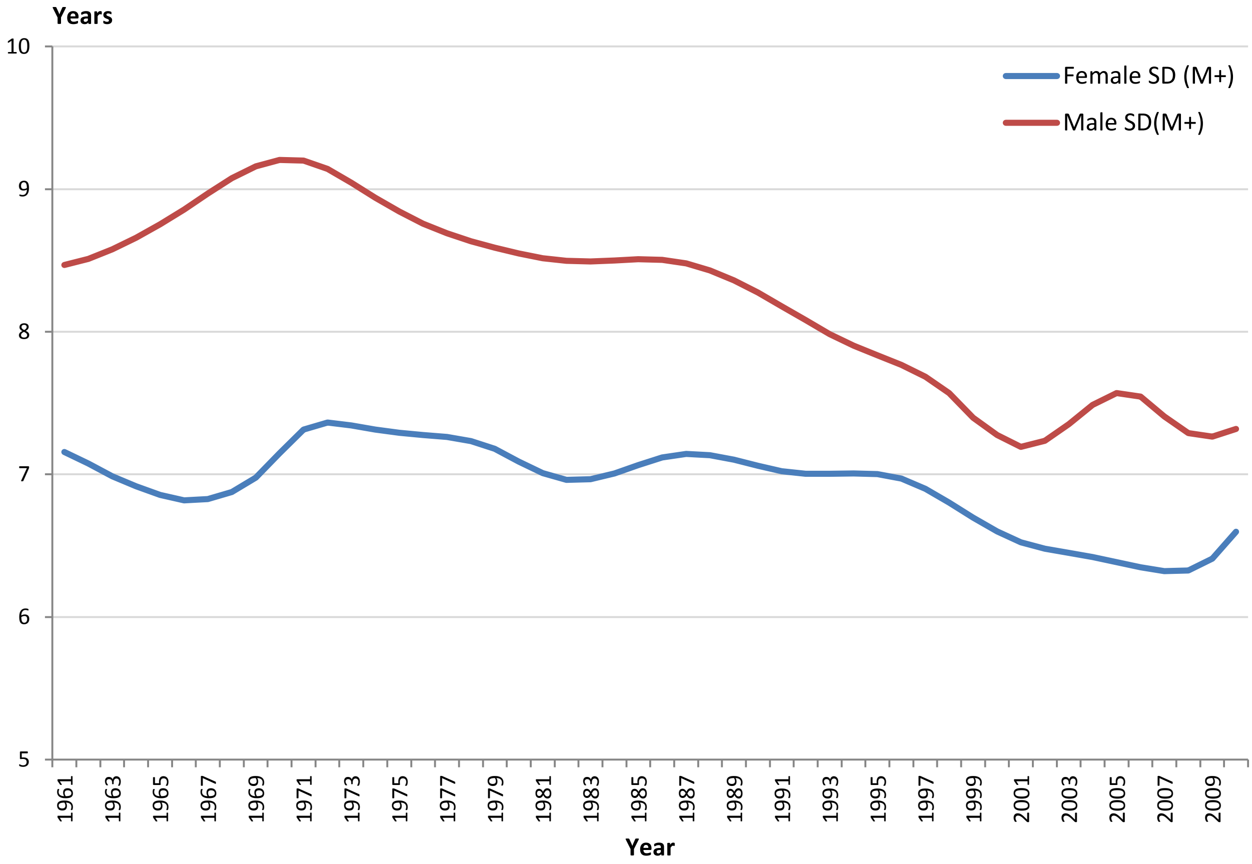
Building on evidence from the previous questions, the third research question concerning the shifting mortality scenario can be introduced. This scenario was first described by Kannisto (1996) and expanded upon by Bongaarts and Feeny (2002, 2003); it is a possible successor to the compression of mortality theory described by Fries (1980), which dominated until the middle of the 20th century. For the second half of the 20th century, the overall compression of mortality has been slow and so the distribution of adult deaths has been dominated by shifts to the right while maintaining shape (Thatcher et al. 2010, 506).

The shifting mortality scenario is defined as the adult mortality or age-at-death distribution shifting to higher ages or the right; deaths above the mode do not narrow into a smaller interval (compression ceases). The characteristics of this would be a stagnation of SD(M+), so the right-hand side of the age-at-death distribution is maintained in shape and the modal age at death would also continue to increase (Ouellette and Bourbeau 2011b).

In section 5.4, discussions showed that although a decrease in SD(M+) had occurred and therefore mortality above the mode had compressed, it is shown to have occurred at a slower pace compared to overall mortality compression. For females in England and Wales, there has been stagnation in SD(M+) for some time now and so it has become necessary to study what is happening to mortality patterns. Ouellette and Bourbeau (2011b) have taken this work forward in most recent years and their work includes data for England and Wales.

Data for England and Wales used in this project demonstrates possible shifting episodes for females in the 1980s and 1990s for about five to six years. During these periods, the mode continued to increase while the SD(M+) stayed the same. Figure 5.6 identifies the two time periods where the SD(M+) stagnates or becomes a horizontal line for females. Looking at the stagnation in the 1980s more closely using data from table 5.1, it is evident that the mode increases throughout the decade. There is an average increase in the mode of 2.2 months for each year from 1980 to 1985. Although this is increasing, it has actually slowed in pace between 1980 and 1985; the pace of improvement in the mode increases from 1987 onward. Overall SD(M) continues to decrease or compress and SD(M+) to one decimal place is maintained at 7.0 years between 1981 and 1984; it is not maintained to two decimal places. Deaths over this time period decrease year on year.

Figure 5.6 Male and female SD(M+), England and Wales, 1961–2010

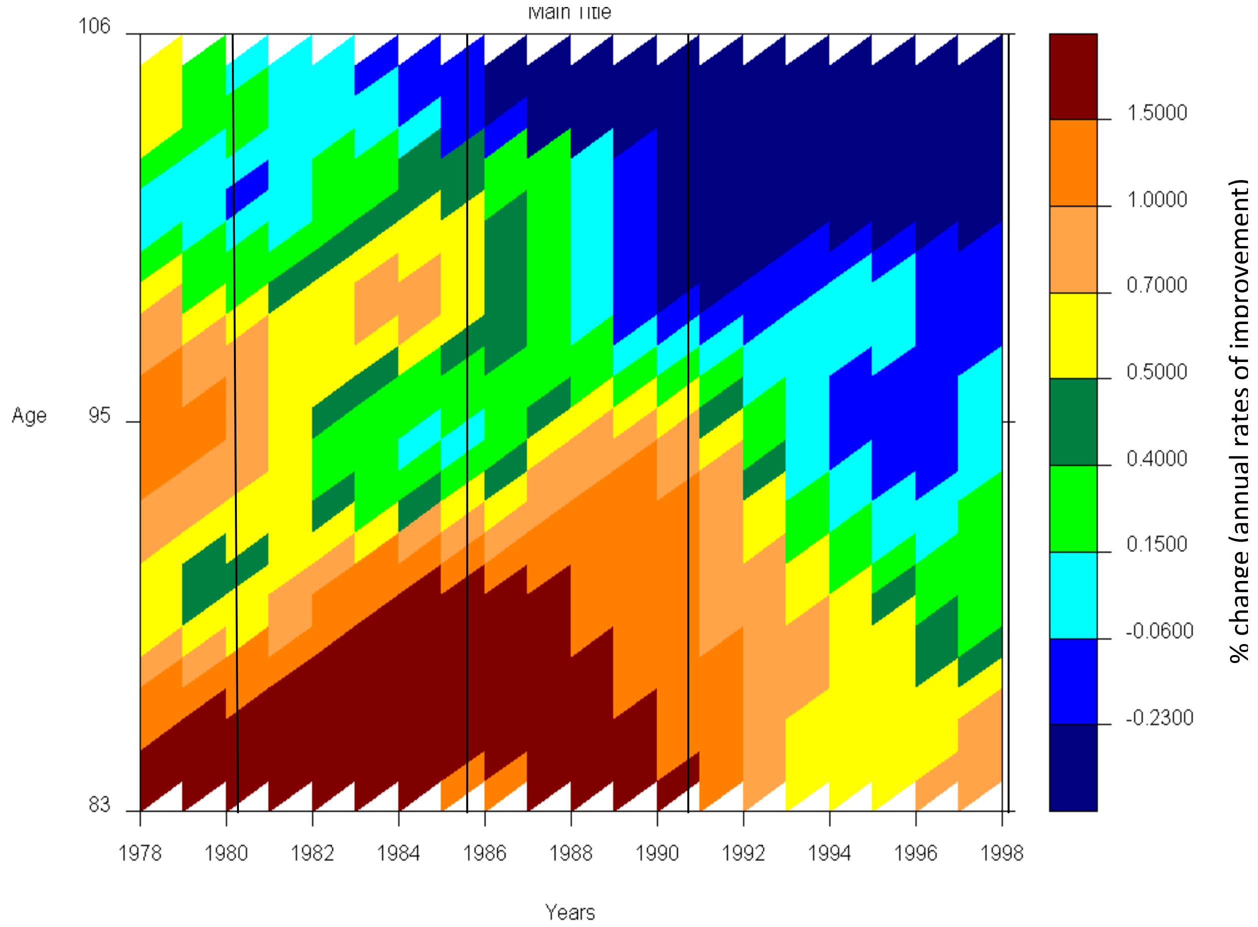


Source: Author's analysis of HMD data

The evidence shows the age-at-death distribution's peak (mode) is slowly moving to the right; it is also decreasing in height. The right-hand side is seen to hold its shape, according to the SD(M+), while the left-hand side continues to compress. As the deaths decrease at the mode, they may shift to older ages; this may explain why SD(M+) to two decimal places increases slightly over this time and into the 1990s. The changes in SD(M) and SD(M+) would mean mortality at and before the mode is improving and so more people die in the years following the mode. This would kick the right-hand side of the age-at-death distribution up and out to the right; this requires the mortality rates (q_x) at the mode to be observed in order to understand the changes in the age-at-death distribution over this time.

Figure 5.7 displays the annual percentage change in the q_x mortality rates by age from the life table. When looking at 1980–85, it is evident the probability of dying was improving around the modal age at death as demonstrated by the brown and orange sections (the q_x is reducing). This means more people were able to survive past the modal age, which in turn means the probability of dying at ages above the mode sees lower levels of mortality improvement as demonstrated by the yellow and green areas.

Figure 5.7 Rates of mortality improvement,* females, England and Wales, 1978–98



Source: Author's analysis of HMD data

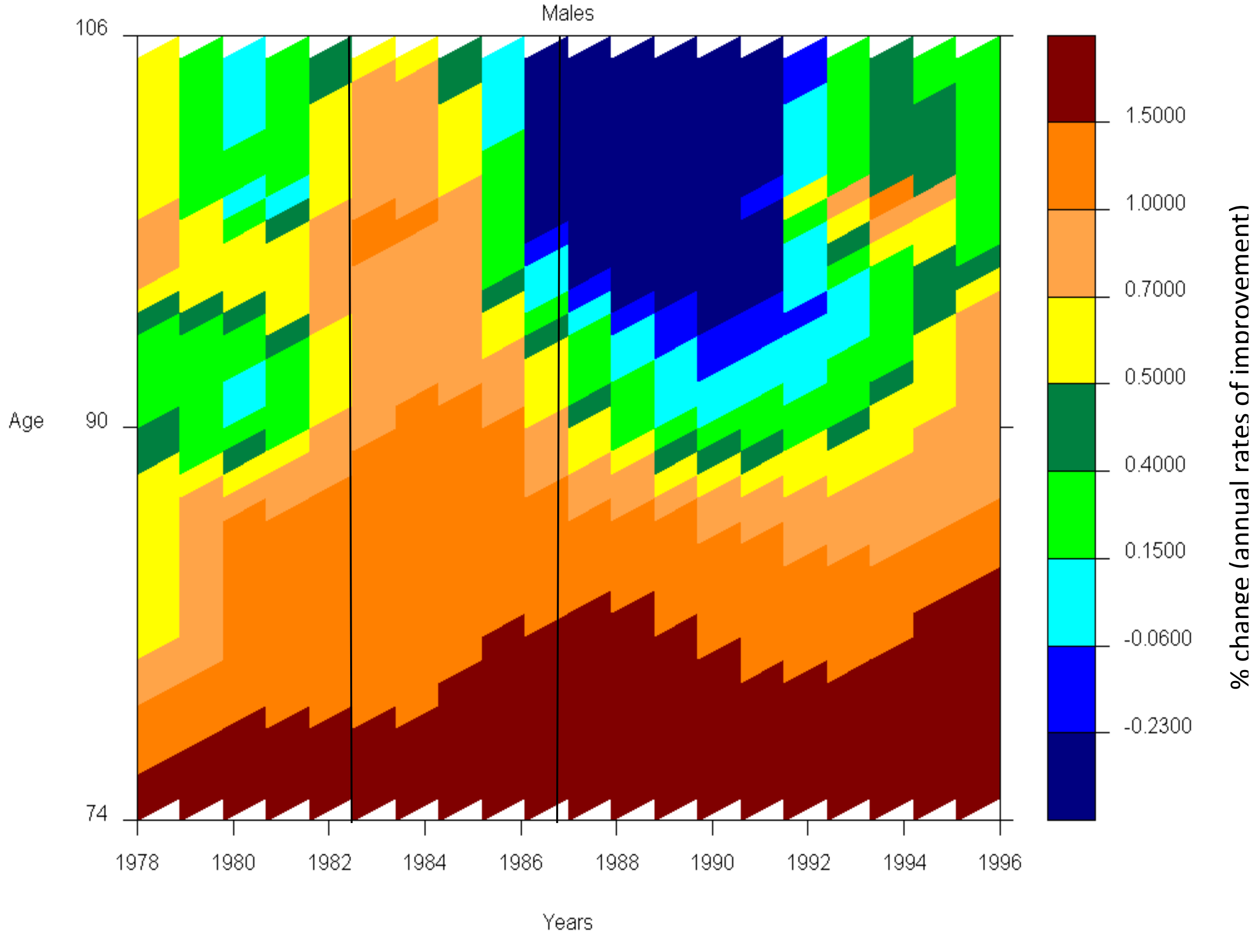
*This heat chart has been constructed using the percent change in the q_x from the life table. This is therefore the change in the probability of dying.

Looking at the same evidence for 1990–97 shows the mode increased each year and, on average, by 1.3 months a year. The SD(M) decreases each year, demonstrating overall mortality compression. The SD(M+) holds at 7.0 years to one decimal place, which is also quite well maintained to two decimal places over the time span. The deaths occurring at the mode increased from 1990 to 1997. The age-at-death distribution is therefore seeing the peak (mode) increasing in height and moving to the right. The SD(M+) suggests the right-hand slope is maintaining its shape while the left-hand slope continues to compress toward the mode. Figure 5.7 shows that the probability of dying around the mode has slowed in the rates of improvement, but the probability of dying has greatly increased at the oldest ages (up to age 106). This suggests that mortality at the mode has stopped improving and more people are able to survive to the oldest ages, which means the probability of dying increases as shown by the blue areas. This also suggests mortality has been able to shift in dominance to the oldest ages during this time period.

For males, stagnation in S.D. above the mode can be seen in figure 5.6 around 1982–86. Taking data from table 5.2, it is evident modal age at death increased over this time period by 2.2 months a year on average. The number of deaths at the mode increases but by a very small number of deaths each year. The SD(M) declines for the first three years of the period and then stagnates at 14.07 years before increasing steadily for the remaining years after 1986; this suggests that even though males had seen overall compression of mortality, it has steadily decompressed in the last 20 years. SD(M+) was constant at 8.5 years to one decimal place after which compression above the mode is observed.

The age-at-death distribution for males from 1982 to 1986 sees a slight increase in height at the peak, and the peak of the curve moves to the right. The SD(M) shows that the left slope moves toward the mode slightly but then maintains its shape, the right-hand slope holds its shape. Figure 5.8 shows that between 1982 and 1986 the probability of dying is improving around the modal age at death (brown areas). It isn’t until the late 1980s and early 1990s that we see the probability of dying at older ages increasing as more people die at these ages. This isn’t prolonged and does not last as it does for females. This suggests that for males, it is only a temporary phenomenon, which is also confirmed by the following decline in SD(M+) whereas in females it is more stagnant.

Figure 5.8 Rates of mortality improvement,* males, England and Wales, 1978–96



Source: Author's analysis of HMD data

*This heat chart has been constructed using the percent change in the q_x from the life table. This is therefore the change in the probability of dying.

The evidence for males and females in England and Wales from this project cannot be definitive in concluding the shifting mortality scenario is occurring in England and Wales.

For the periods identifying stagnation in SD(M+), the evidence is not strong enough to suggest that England and Wales is demonstrating a shifting mortality scenario. Though SD(M+) stagnates and the modal age at death increases, overall compression of mortality continues and the number of deaths at the mode changes (increases or decreases), which would mean that the area under the age-at-death distribution curve would change shape rather than shift position. The periods of stagnation do not occur for as long as they do in other countries, for example Japan, nor do any countries display a shifting mortality scenario for males other than for Japan (Ouellette and Bourbeau 2011b).

The Lexis heat charts in figures 5.7 and 5.8 suggest the probability of dying at older ages is increasing as greater numbers die at those ages; this has especially continued for females over recent years. Females in England and Wales are showing more evidence that a shifting mortality scenario is probable in the near future; this is because the SD(M+) and SD(M) are slowing or stagnating. The number of deaths occurring at the mode are also slowing in their pace of increase in recent years (figure 4.2). Robine et al. (2008, 11) describe "an intermediate situation between mortality compression and mortality shift, where a steady increase in the modal length of life is accompanied by a modest decrease in the standard deviation of the ages at death above the mode." Females in England and Wales may well be in this intermediate situation.

5.6 Summary

In answer to the question "How has the S.D. of ages at death around and above the mode changed over time?" we have learned the following.

The SD(M) has decreased for both males and females in England and Wales between 1841 and 2010. This means that overall mortality has compressed into a shorter age range, which is also demonstrated by the age-at-death distribution curves becoming narrower. This is what Fries (1980) discussed, although human populations have exceeded the proposed modal age at death. The levels of mortality compression that Fries proposed have not been reached. The right-hand slope of the age-at-death distribution has become steeper, which has in turn encouraged researchers to separate overall mortality compression from old age mortality compression (Thatcher et al. 2010); this means it has also become important to look at the distribution of deaths above the mode through the use of the SD(M+). SD(M+) for males and females has also decreased over time, demonstrating compression of mortality above the mode. This is caused by the continuing improvements in the modal age at death, which occur at a faster pace compared to improvements in mortality at the oldest ages (Thatcher et al. 2010, 527). Alternative measures also confirm the trends seen in SD(M) and SD(M+).

As to England and Wales demonstrating a shifting mortality scenario, periods in the 1980s and 1990s can be identified where the SD(M+) had stagnated and the modal age at death was increasing for males and females. Although these periods could be identified as shifting mortality periods, the remaining evidence, as discussed in this section, does not suggest these are periods characteristic of the shifting mortality scenario. Females in England and Wales are more likely to be demonstrating an “intermediate situation” where modal age at death is increasing steadily and the SD(M+) is seeing a modest decrease. Neither males nor females have reached the point where the height and shape of the age-at-death distribution is maintaining its shape and simply shifting to the right. The next section will discuss how these findings compare to other studies and the strengths and weaknesses of the methodology used.

Table 5.1 Various measures, female, England and Wales, 1961–2010

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
SD (M)	14.24	14.33	14.44	14.55	14.65	14.73	14.76	14.74	14.67	14.52	14.38	14.34	14.35	14.37	14.37	14.36	14.35	14.35	14.38	14.44	14.49	14.51	14.48	14.42	14.34
SD(M+)	7.16	7.08	6.99	6.92	6.86	6.82	6.83	6.88	6.98	7.15	7.32	7.36	7.34	7.31	7.29	7.28	7.26	7.23	7.18	7.09	7.01	6.96	6.97	7.01	7.07
Death	3952	3950	3939	3931	3910	3878	3842	3797	3754	3729	3729	3758	3808	3867	3922	3960	3976	3966	3938	3901	3882	3866	3854	3845	3838
Mode	81.46	81.73	82.08	82.42	82.76	83.03	83.17	83.19	83.07	82.79	82.51	82.48	82.61	82.75	82.90	83.03	83.18	83.38	83.64	83.99	84.31	84.55	84.68	84.72	84.73

Source: Author's analysis of HMD data

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
SD (M)	14.27	14.22	14.21	14.21	14.22	14.22	14.18	14.13	14.06	14.00	13.96	13.96	13.98	14.01	14.04	14.05	14.03	14.00	13.97	13.96	13.95	13.94	13.93	13.86	13.74
SD(M+)	7.12	7.14	7.13	7.10	7.06	7.02	7.00	7.00	7.01	7.00	6.97	6.90	6.80	6.70	6.60	6.52	6.48	6.45	6.42	6.38	6.35	6.32	6.33	6.41	6.60
Death	3830	3821	3811	3810	3814	3820	3831	3846	3865	3886	3909	3935	3972	4010	4045	4078	4109	4126	4133	4135	4141	4154	4174	4209	4266
Mode	84.75	84.83	84.98	85.18	85.38	85.55	85.66	85.70	85.72	85.76	85.84	86.02	86.28	86.56	86.84	87.09	87.28	87.47	87.67	87.89	88.12	88.34	88.51	88.58	88.53

Table 5.2 Various measures, males, England and Wales, 1961–2010

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
SD(M)	14.07	14.10	14.15	14.21	14.29	14.36	14.42	14.48	14.52	14.55	14.59	14.66	14.77	14.95	15.08	15.16	15.11	14.99	14.85	14.77	14.79	14.92	15.06	15.12	15.10
	14.38	14.38	14.37	14.37	14.34	14.30	14.22	14.13	14.04	13.97	13.93	13.94	13.98	14.03	14.08	14.11	14.13	14.14	14.13	14.13	14.12	14.11	14.09	14.07	14.06
SD(M+)	8.50	8.48	8.43	8.36	8.28	8.18	8.08	7.98	7.90	7.84	7.77	7.68	7.57	7.40	7.28	7.19	7.24	7.35	7.49	7.57	7.54	7.41	7.29	7.26	7.32
	8.47	8.51	8.58	8.58	8.75	8.86	8.97	9.08	9.16	9.20	9.20	9.14	9.05	8.94	8.84	8.76	8.69	8.64	8.59	8.55	8.52	8.50	8.49	8.50	8.51
Deaths	3533	3532	3536	3540	3542	3552	3564	3575	3592	3608	3619	3625	3632	3638	3655	3671	3694	3711	3727	3745	3768	3804	3875	3929	3952
	3433	3422	3407	3407	3382	3378	3386	3404	3428	3454	3480	3501	3516	3534	3548	3555	3552	3550	3545	3536	3528	3525	3527	3530	3532
Mode	77.80	78.02	78.29	78.59	78.92	79.25	79.59	79.92	80.21	80.48	80.77	81.11	81.53	82.11	82.59	83.00	83.13	83.13	83.09	83.18	83.50	84.07	84.63	85.05	85.44
	75.22	75.20	75.19	75.19	75.11	75.03	74.89	74.74	74.60	74.53	74.56	74.70	74.94	75.20	75.46	75.72	75.96	76.19	76.43	76.67	76.90	77.11	77.29	77.45	77.61

Source: Author’s analysis of HMD data

6 Discussion

6.1 Introduction

The remaining research question is approached in this section. It is followed by a critical discussion surrounding the findings of this project. The section contextualizes the results within existing literature, discusses the strengths and weaknesses of the methodology used and explores the relevance of the results for gerontological issues in the future.

6.2 Is modal age at death a more appropriate measure than life expectancy for England and Wales?

Life expectancy is the mean age at death according to the life table (hypothetical population) distribution of deaths. It is the most popular and historic method used to describe the health and mortality of a population. The modal age at death, which has gained recognition recently because of changes in the age-at-death distribution, is the most common age at death, or the age at which most deaths occur in a population. Life expectancy behaves like a mean and is therefore affected by extremes; for example, high levels of infant mortality would pull the life expectancy at birth down. The mode is solely influenced by changes to mortality at the oldest ages, and it is identified that "modal age at death is the most central and natural characteristic of human longevity" (Ouellette and Bourbeau 2011a, 597). Studying the mode allows the understanding of the changes in the age-at-death distribution; because the age-at-death distribution is not symmetrical (negatively skewed), the L.E. provides less detail compared to the mode. According to Canudas-Romo (2008, 1195), "In low mortality countries the modal age at death can be an important reference point to study deviations in mortality not perceived in the life expectancy change."

There is a risk that in low mortality countries such as England and Wales, which also has an aging population, L.E. can underestimate realistic life spans. This is also true of the mode because the age-at-death distribution is bimodal, which means that if deaths at younger ages are included in the data, there would be a peak of deaths just after birth and then again at the late modal age at death. This emphasizes the important difference of measuring life expectancy at birth, including the high risk of dying within the first year of life and then measuring life expectancy once this risk has been removed. The mode naturally lends itself to measurement of life expectancy in populations where improvements in mortality are being made at the oldest ages.

In answering the research question above, it is concluded the mode should be used within a combination of measures of life span in future analysis. L.E. has become less informative for an aging population over time but it is still a universally understood measure. It is recommended a combination of methods be considered, with the selection of the measure (mean, median or mode) to be made according to which measure is the most appropriate to the population age structure and age-at-death structure being studied as each indicator reacts differently depending on whether mortality rates reduce above or below the chosen measure.

6.3 Findings of this report

The aims of this report were to understand how the modal age at death and the age-at-death distribution for males and females in England and Wales had changed over time by studying deaths at the mode, SD(M), and above the mode, SD(M+). The ultimate aim was to understand if, after the compression of mortality, England and Wales had entered the new stage of the shifting mortality regime.

In sections 4 and 5, results were provided to show that the modal age at death had increased and had become more common over time. There had been overall mortality compression and the mortality above the mode had also compressed but at a slower pace. Evidence suggested England and Wales had not yet entered a shifting mortality regime, but females are probably closest to seeing this in the near future.

The findings from this project are in-line with similar studies. Ouellette and Bourbeau (2011a) also reported a sustained upward linear trend in the mode for females, and Thatcher et al. (2010) found that the increases for males did not start before 1970. Although Canudas-Romo (2008) concluded the modal age at death in England and Wales changed at a more modest pace compared to other countries, which cannot be compared to these findings, he commented that the increase in number of deaths at the mode could be the transition from rectangularization to the shifting mortality regime. This is conferred from the data in this project, especially for females.

All authors of current research similarly concluded that overall mortality compression and mortality compression at the oldest ages had been seen in low mortality countries. Thatcher et al. (2010, 527) found "there had been mortality compression above the mode." As the mode increased, there has also been a reduction in the variation in the length of life. This is consistent with findings in Institute and Faculty of Actuaries (2012, 6): "Much of the reduction in variation in age at death over recent decades has been because deaths at young ages have reduced. And as a single mode of the age-at-death distribution becomes more pronounced, so compression of mortality is consistent with a reduction in variation." This is also indicated by the number of deaths increasing at the mode. Canudas-Romo (2008, 1182) had similar findings for the Netherlands as this report for the percentage of deaths occurring at the mode: "The modal number of deaths changed from 2.3 percent of all deaths in 1900 to be 4.2 percent in 2000."

With regard to the findings surrounding males and females in England and Wales and the shifting mortality scenario, it is harder to compare findings with recent studies. The most similar work comes from Ouellette and Bourbeau. They mainly focus on Japan, but do state, "Females from some of the other countries have also been through such shifting episodes between 1950 and 2006 or 2007, but none has experienced one for as many successive years as the Japanese's" (2011b, 12). England and Wales are included in their study, but the focus on these countries is minimal and therefore it is hard to deduce whether England and Wales are one of these countries. The findings in this report suggest that the evidence for females is not strong enough to have demonstrated shifting periods and especially not for males. One similarity of these findings to other work is that England and Wales have not reached the situation that Japanese males and females are currently in with regard to their age-at-death distribution.

6.4 Strengths and weaknesses

Different methodologies provide different strengths and weaknesses. Smoothing mortality rates using two-dimensional P-splines makes the assumption that death counts are Poisson counts; the advantage of smoothing mortality rates in comparison to applying a model to the data is that it does not place any rigid assumptions on the data. This is discussed in section 3. Period data was used in this project, and is commonly used in modal age-at-death studies to identify the changes in mortality over a time period. Cohort data is harder to use as there is not enough detailed information about projected mortality for those cohorts still alive. It is argued by Ediev (2011, 3) that "the period life table model, which is widely used to address mortality compression, produces an artificially compressed picture of mortality as a built-in feature of the model." The findings using cohort analysis found that mortality above the mode was in fact decompressing, producing different implications for the age-at-death distribution to what is found when using period data.

Using SD(M+) focuses on deaths above the mode only; this can be considered a disadvantage as it ignores large parts of mortality experiences. This focus was inspired by Lexis's assumption that natural deaths were normally distributed. More recent evidence has suggested this model can be outperformed by Kannisto's logistic model and associated methods (Ediev 2011, 9).

Assumptions made and noted in section 3 also need to be considered alongside the overall quality of the data. The data source is credible and death registrations are compulsory in England and Wales, making the death counts robust. Population estimates are likely to be most reliable in more recent years. This is because more sophisticated methods are used to fill in years between censuses and rebasing of estimates has occurred between census years. With regard to producing estimates for ages 90+, it is important to consider the methodology ONS has used—the Kannisto-Thatcher method (ONS 2011b). Uncertainty is introduced by removing data to smooth mortality rates and then extrapolating this back to age 125. This is one of the points where error could be introduced into the data, although Q.A. should keep the error to a minimum. It is also important to consider the researcher's role in influencing the data and methodologies chosen. Working for the Office for National Statistics means methods and sources are influenced by peers and limitations within ONS.

6.5 Impact of the findings from this report

The findings from this report add to the evidence of an aging population, helping to identify the impact of improving mortality at mid to older ages, and how this has accelerated in more recent years. The compression of mortality indicates that the span of time in which deaths occur is reducing and life spans become more homogenous. The variation in life spans above the mode has not reduced as much.

Evidence gathered here can feed into planning and policies surrounding pensions, housing, health care, social care and service provision. Because calculations of the mode remove mortality at younger ages and are solely influenced by mortality changes at the oldest ages, higher estimates of life span compared to L.E. at birth are produced. This is of key importance with regard to planning and policies in an aging population where accurate and realistic measurements of length of life are crucial, particularly for pensions and long-term care.

This evidence will feed into the mortality assumptions produced by the Office for National Statistics and into national population projections (ONS 2012a). The population projections allow the government and local authorities to prepare for the age structures they will deal with in the future. This then influences the levels of funding a local authority receives from central government. The findings of this report also feature in ONS (2012c).

Modal age-at-death studies are useful for comparing mortality, health and aging between countries. Future work in this area would ideally look at projecting modal age at death, taking into account the possible shifting mortality scenario to allow the accurate analysis of likely life spans as males and females in England and Wales reach adulthood. Other future work would also include comparisons of the countries in the United Kingdom, particularly Scotland, which would help shed light on differing life expectancy figures.

6.6 Summary

The mode should be used within a combination of measures of life span in future analysis. Life expectancy cannot be disregarded entirely, and a method for analyzing health and mortality should be selected according to the characteristics of the population being studied.

The results from this report are found to be in-line with similar studies. The findings surrounding males and females in England and Wales and the shifting mortality scenario are harder to compare as other recent studies have not solely focused on England and Wales.

It is acknowledged that methodologies chosen have their own strengths and weaknesses. Some data and methodologies can introduce error or alter the reliability of the data. It is also important to consider the impact ONS has on the results. The findings of this report can build on evidence of an aging population and feed into reports and funding surrounding pensions, housing, health care and service provision. The next section will conclude the report.

7 Conclusion

Mortality in England and Wales has changed dramatically since 1841. As the pattern of mortality shifts to older ages, it moves away from overall mortality compression and so the mean measure of life duration (L.E.) has become less meaningful. Modal age at death has emerged as a suitable alternative measure in low mortality countries.

Midyear population estimates and deaths in England and Wales have been smoothed using the software R to produce mortality rates used to construct period life tables. Modal age at death after age 10 for the civilian population has been extracted for the years 1841–2010 for males and females separately.

The four proposed research questions (section 1) have produced findings that show modal age at death has increased since 1841. For females, this has been gradual since 1900 but more rapid for males since 1970. SD(M) has shown that mortality has compressed into a shorter age interval, and SD(M+) has shown that mortality above the mode has compressed slightly but has stagnated for females in recent years.

Evidence suggests England and Wales have not demonstrated a shifting mortality scenario but females are demonstrating an intermediate situation. Modal age at death is a useful measure in low mortality countries where aging is a key feature. It should be used in conjunction with other measures to fully understand mortality changes over time. The findings from this report are in-line with findings of other authors, including Ouellette and Bourbeau and Thatcher et al., and will feed into work by ONS surrounding mortality assumptions for national population projections and planning based on population age structure, pensions, services, and health and social care provision.

It is recommended ONS use the technique detailed in this report to gain an understanding of the impact and outcomes of the projections made about mortality and life expectancy into the future for England and Wales and the United Kingdom. This could be a tool used to ensure the projections made by ONS are tested rigorously and produce viable projections for future mortality. Initial results for the United Kingdom have been produced using the 2010-based mortality projections (appendix IV); these results will inform and be a comparator to the 2012-based projections ONS is currently producing.

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Appendices

I List of datasets used (in .csv format)

Country	Population	Type	Sex	Starting age
England and Wales	civilian	deaths	female	10
England and Wales	civilian	deaths	female	0
England and Wales	civilian	deaths	male	10
England and Wales	civilian	deaths	male	0
England and Wales	civilian	population	female	10
England and Wales	civilian	population	female	0
England and Wales	civilian	population	male	10
England and Wales	civilian	population	male	0
England and Wales	total	deaths	female	10
England and Wales	total	deaths	female	0
England and Wales	total	deaths	male	10
England and Wales	total	deaths	male	0
England and Wales	total	population	female	10
England and Wales	total	population	female	0
England and Wales	total	population	male	10
England and Wales	total	population	male	0

II Syntax for R: MortalitySmooth run for males and females separately

```
library(MortalitySmooth)

        deaths<-as.matrix(read.csv(“path\\path\\path\\deaths.csv”,header=FALSE))

        exposure<-as.matrix(read.csv(“path\\path\path\\exposure.csv”,header=FALSE))

        ages<-c(?:?) (NOTE: Ages changed according to which datasets were being smoothed)

        years<-c(1841:2010)

fit<-Mort2Dsmooth(x=ages,y=years,z=deaths,offset=log(exposure))

mx.smooth<-(fit[23]$fitted.values/exposure)*100000

write.csv(mx.smooth,file=”path\\path\\path\\mx_smooth.csv”,quote=FALSE)
```

III Syntax for Excel

Example taken from females, 2002.

Standard deviation around the mode:

Column 1: =(AIH$2-AIG91)*AIH91*((AIH$2-AIG91)/2)^2

Column 2: =(AIG92-AIH$2)*AIH91*((AIG92-AIH$2)/2)^2

Column 3: =AII91+AIJ91

Standard deviation above the mode:

Column 1: =(AIG135+1-AIH2)*AIH91

Column 2: =(AIG135+1-AIH$2)/2

Column 3: =AII135*AII135

Column 4: =AIJ135*AIH135

IV Initial results for U.K. mortality projections

Introduction

The analysis was extended to look at the ONS 2010-based mortality projections data. The analysis was used to understand more about the patterns and trajectories in the projection period. Normally this work would be carried out by looking at patterns within the mortality rates and life expectancies alone but, on this occasion, an analysis of what happens to the age-at-death distributions and the mode, as a consequence of the assumptions made in the projections process, was also performed.

Methodology

The same method used in the main analysis was applied in this projections analysis. Due to availability of data, data was used for the United Kingdom as a whole. The main focus was the years 2010–2109 (the full projections period).

Midyear population estimates and deaths for the years 1961–2109 for males and females separately were smoothed using the MortalitySmooth package in the software R.

Data was smoothed from age 10 to 104 for both males and females; the resulting M_x mortality rates were extrapolated to age 125 and converted into a q_x probability of dying.

The q_x values were then used to construct a life table; the deaths (d_x) were extracted and ordered to obtain the modal age at death; this was then further refined using formula 3.2. This provides the modal age at death to 4 decimal places by fitting a quadratic polynomial to the death distribution data.

Standard deviations around the mode, SD(M), and standard deviations above the mode, SD(M+), were calculated using the same method as described in section 3.

It is to be noted that the midyear population and the deaths data for the projection years (2010–2109) will be based not only on the assumptions made about mortality but also those surrounding fertility and migration. More information can be obtained from the ONS website.[3]

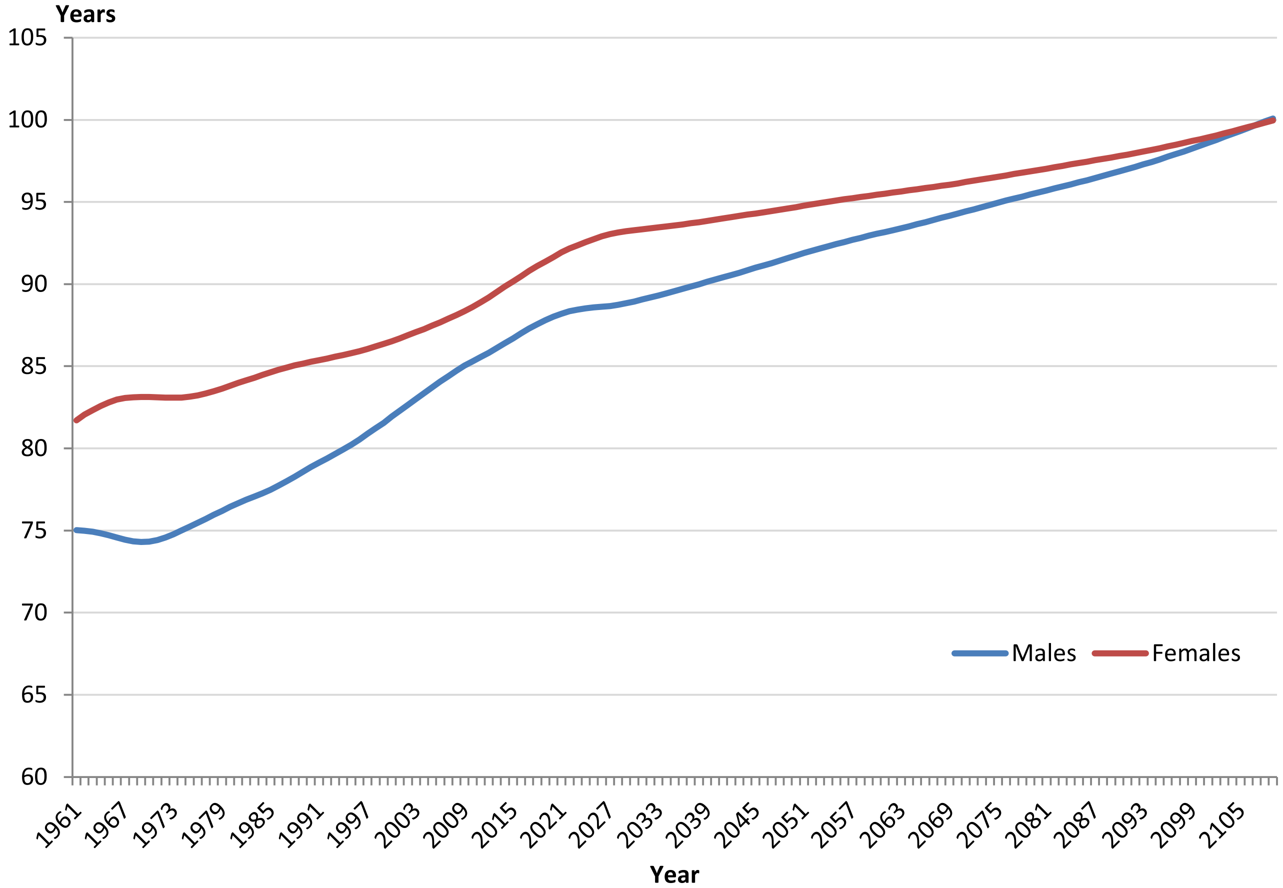
Results

The following graphs present some of the findings from the analysis; they have a particular focus on the projection period (2010–2109).

Figure A.1 shows a smoother, more gradual increase in the mode compared to what is seen in figure 4.1. The modal age at death (mode) clearly converges until the year 2021, after which we see the divergence of male and female modal age at death until 2039. From 2039 onward, the modal age at death converges until they meet at age 100 by the end of the time period. The two points meet as a result of setting the same target rate for mortality improvements for both males and females by 2037. The ONS projections clearly show a continued projected increase in the modal age at death for the United Kingdom.

[3] http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2010-based-reference-volume--series-pp2/index.html

Figure A.1 Late modal age at death, United Kingdom, 1961–2109

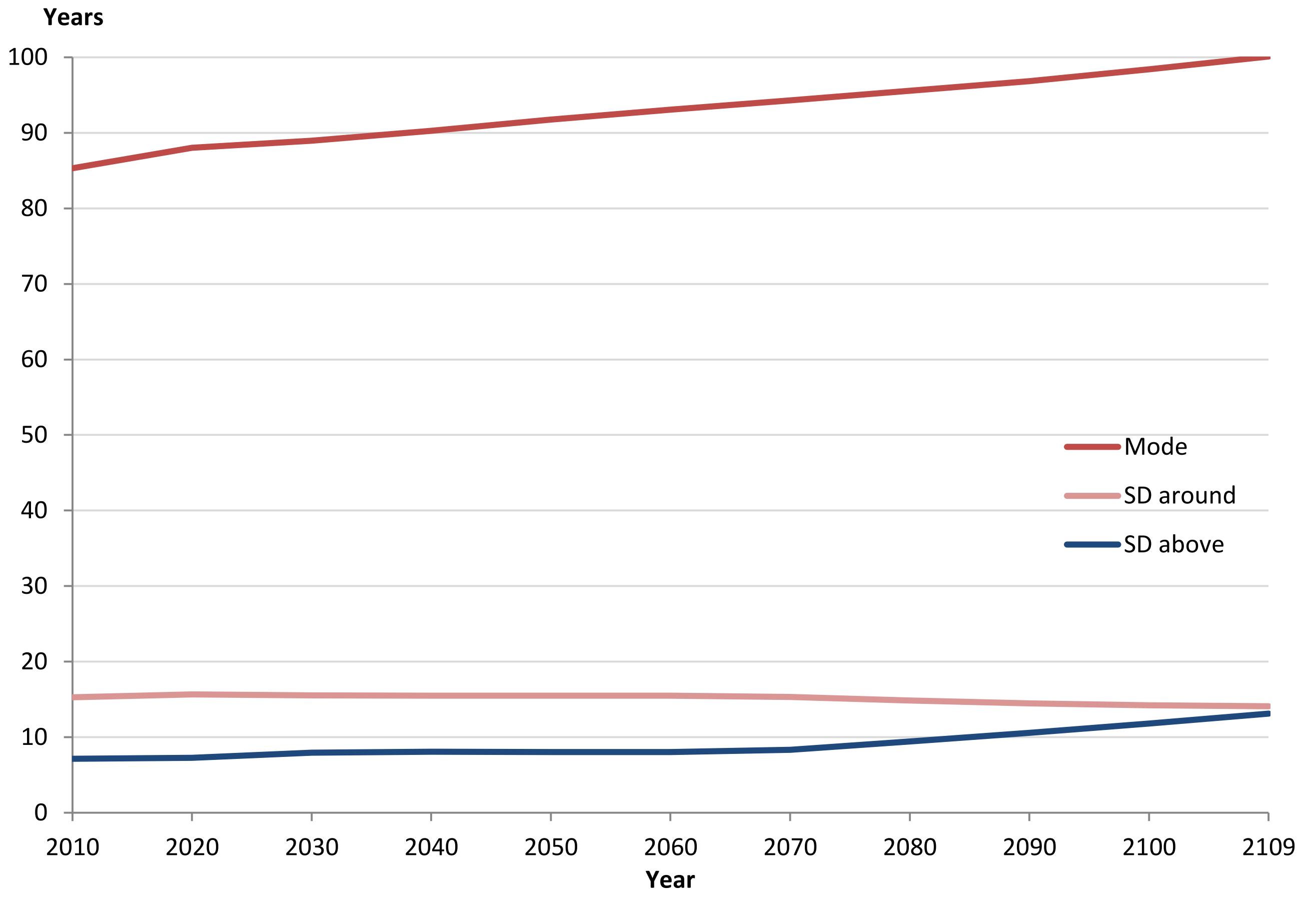


Source: Author's analysis of ONS data

Figures A.2 and A.3 present the mode along with the standard deviation around the mode and the standard deviation above the mode. For both males and females, the SD(M) stays relatively constant; males start at 15.3 years, peak at 15.6 years and then fall to 14.1 years by 2109. For females, SD(M) starts at 13.7 years, peaks at 14.5 years and then falls to 12.5 years by the end of the period. As the mode continues to increase, the SD(M+), after stagnating for the first 50 years of the time period, increases for both males and females and then reaches similar levels as the SD(M) by 2109.

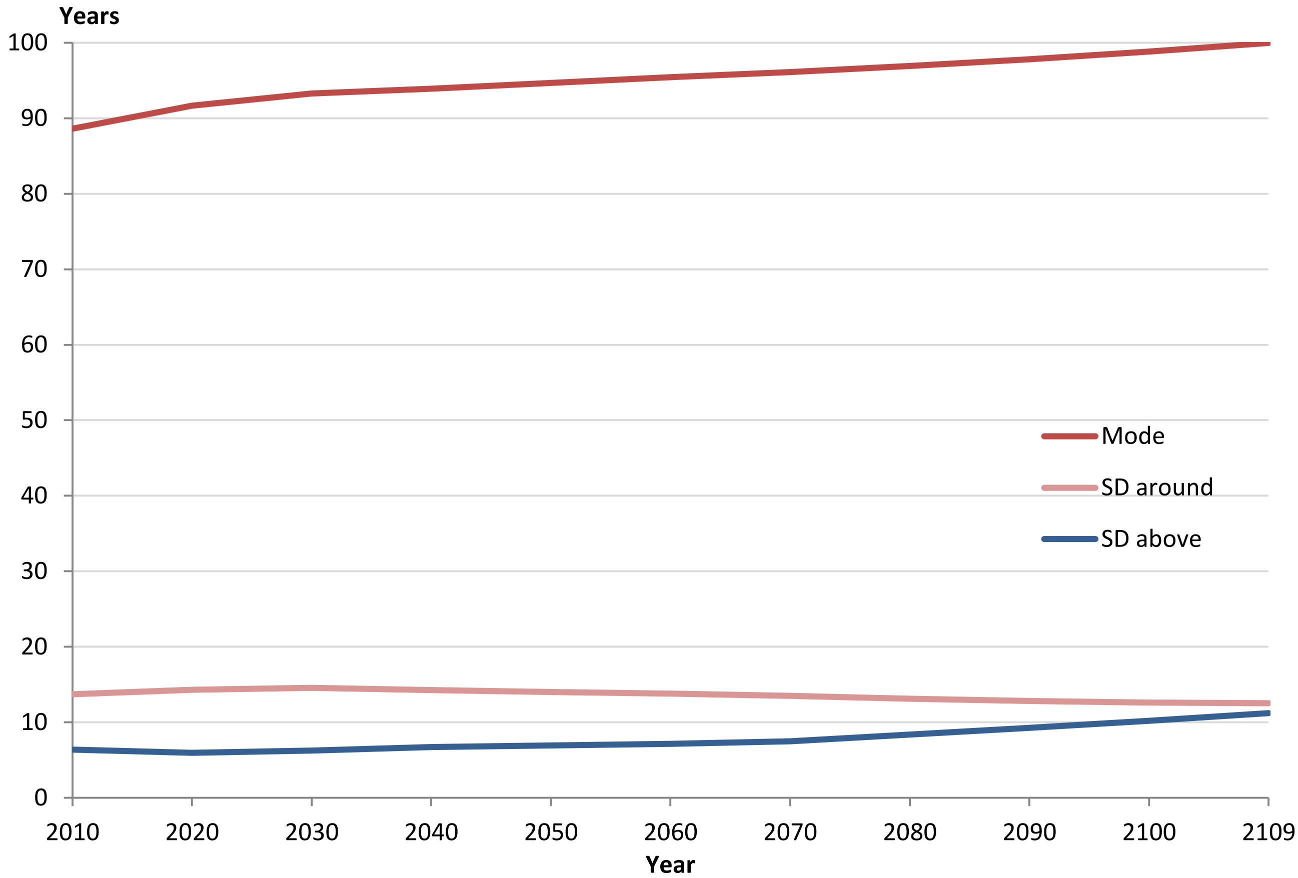
Deaths above the mode in the projection period are becoming more dispersed. For both males and females, as the duration of life continues to increase, variation in life span above the mode begins to increase.

Figure A.2 Male modal age at death, SD(M) and SD(M+), United Kingdom, 2010–2109



Source: Author's analysis of ONS data

Figure A.3 Female modal age at death, SD(M) and SD(M+), United Kingdom, 2010–2109



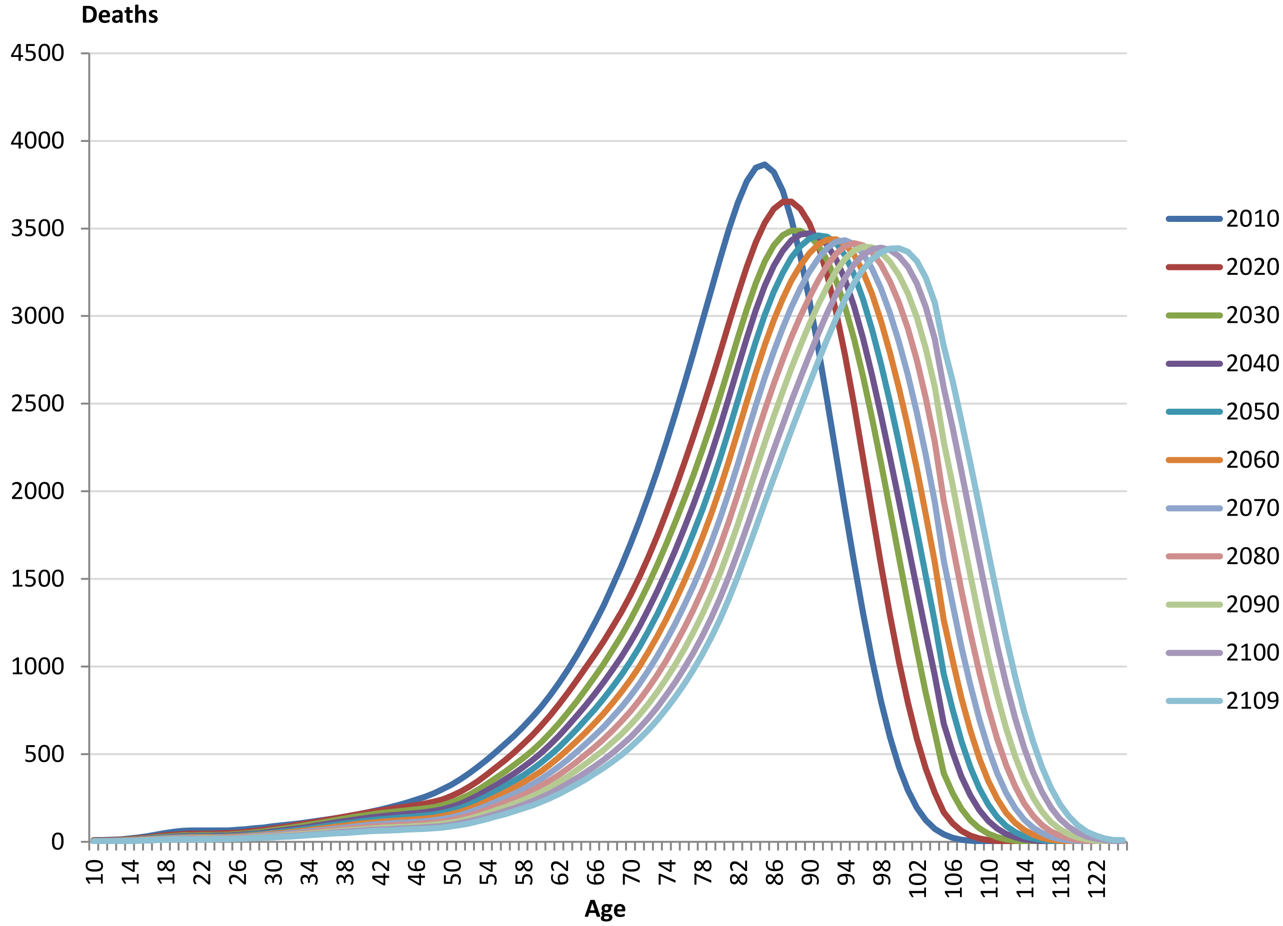
Source: Author's analysis of ONS data

Figures A.4 and A.5 show the age-at-death distributions for the projection period. For males and females, it is clear that deaths at the mode, the peak of the graph, fall for the first 20 years, after which they remain quite consistent for males but continue to fall for females.

The increases in the mode are clearly demonstrated as the peak of the curve moves to the right. The SD(M+) is known to be increasing, as shown in previous figures; this would suggest that as the height of the peak decreases and moves to the right, the area to the right of the curve is also increasing as variation in life span above the mode increases.

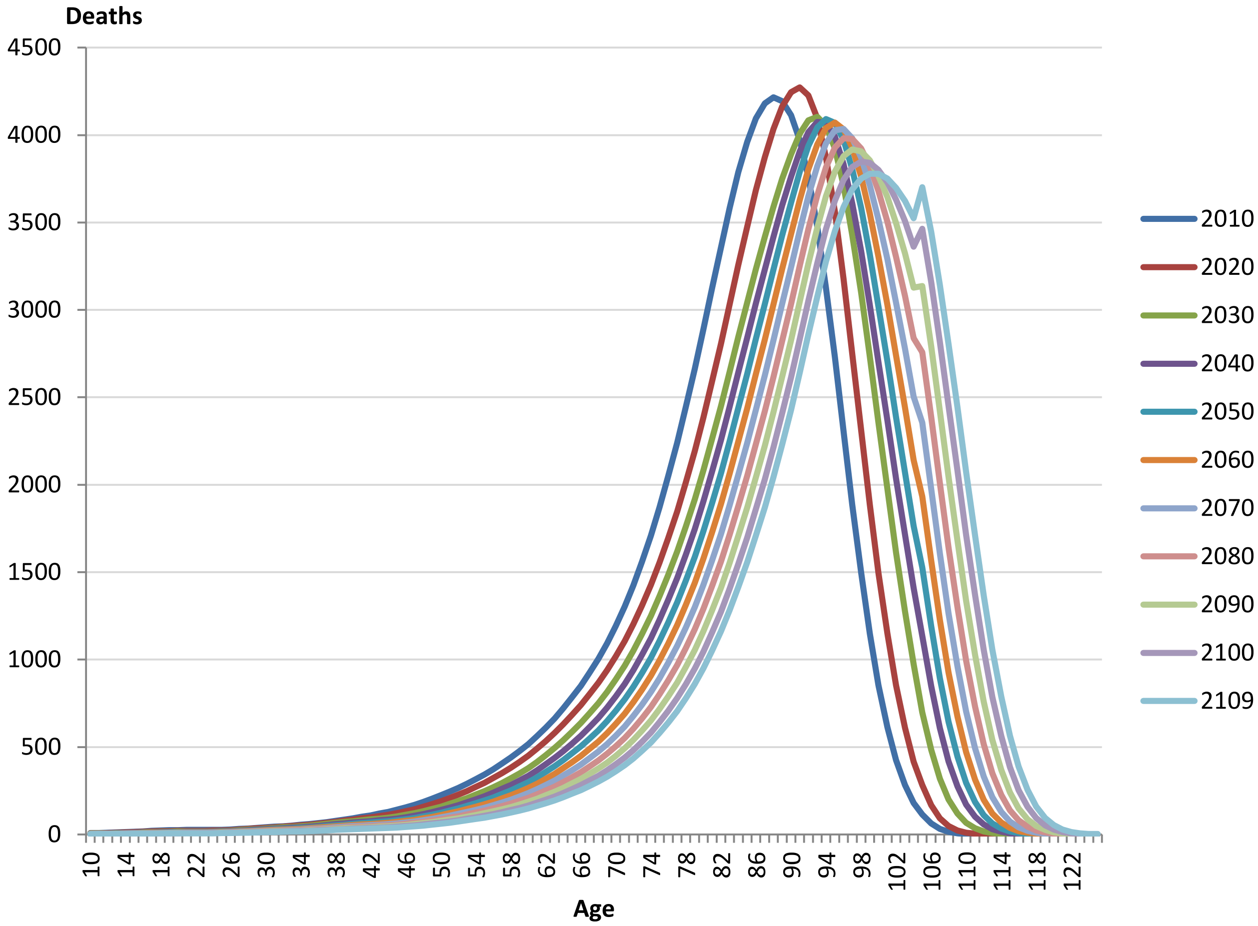
The application of consistent rates of mortality improvement means that mortality at the older ages continues to improve and so we see more deaths at the oldest ages. More variation is seen in these deaths at older ages as the deaths occurring at the mode fall.

Figure A.4 Male deaths, United Kingdom, 2010–2109, selected years



Source: Author's analysis of ONS data

Figure A.5 Female deaths, United Kingdom, 2010–2109, selected years



Source: Author's analysis of ONS data

Note: A spreadsheet error was discovered in the 2010-based projection mortality improvement rates for females; this was not corrected for and is evident in figure A.5.

Conclusion

The evidence presented in the figures above suggest the possibility of a third scenario, which succeeds the compression of mortality and shifting mortality scenario. The third scenario is the de-rectangularization of the survival curve (Kachakhidze 2011b). The characteristics of this phase are an increase in SD(M+) along with an increase or stagnation in the modal age at death. These characteristics are clearly demonstrated within the resulting data from the ONS 2010-based projections.

The small project presented here has been used to inform the mortality projections process at ONS by giving an insight into the consequences of setting and projecting certain assumptions. ONS clearly produces projections rather than predictions and so the results shown above are purely a scenario that could occur if the assumptions set were to happen.

Emily Clay

In 2009, Emily graduated from the University of Southampton with a bachelor of science with honors in population science. She gained a post as a research officer at the Office for National Statistics (ONS) and spent over two years working in the census unit, designing and consulting on the outputs for the 2011 census. She is currently working in the demographic analysis unit, specializing in mortality and longevity. After completing further studies at the University of Southampton, she was awarded a master of science in gerontology with distinction. The modal age-at-death research project is part of her work at the ONS and was the topic of her master’s degree dissertation.